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A-10 STATIC STRUCTURAL TEST PROGRAM.(U)

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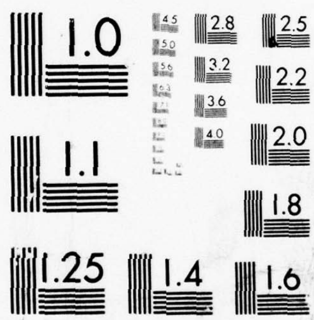

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A-10 STATIC STRUCTURAL TEST PROGRAM

STRUCTURES TEST BRANCH
STRUCTURAL MECHANICS DIVISION

February 1979

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Final Technical Report

"Approved for public release; distribution unlimited."

AIR FORCE FLIGHT DYNAMICS LABORATORY
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The Fairchild Republic Company A-10 aircraft was subjected to a complete static structural test program covering all the critical flight, landing, and ground handling conditions. There were 79 separate test conditions in this test program. Four of these conditions were selected to be run as failing loads tests at the conclusion of the test program. There were no major structural failures of the primary structure. There were some failures and design deficiencies in secondary structure.

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FOREWORD

This report was prepared by the Air Force Flight Dynamics Laboratory as a formal record of the complete structural test program for the A-10 aircraft. The structural tests reported were conducted by the Structures Test Branch, Structural Mechanics Division, AF Flight Dynamics Laboratory, Wright-Patterson AFB, OH. The program was conducted under AFFDL Job Order No. 329A5002, by Mr. Thomas F. Hughes, Senior Project Engineer, Mr. Martin D. Richardson, Project Engineer, Mr. Frederick E. Hussong, Senior Instrumentation Engineer, and Messrs. David Erskine and Lawrence Kretz, Instrumentation Engineers.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF TABLES

LIST OF SYMBOLS & ABBREVIATIONS

DLL	Design Limit Load
DUL	Design Ultimate Load
S.O.P.	Standard Operating Procedure
C.P.	Center of Pressure
F.S.	Fuselage Station
OTEFS	Outboard Trailing Edge Flap Station
B.L.	Buttock Line
W.S.	Wing Station
FRC	Fairchild Republic Company
M.S.	Margin of Safety
V	Sensor or transducer bridge input voltage
E	Modulus of Elasticity
ΔE	Change in sensor or transducer output voltage
ΔE_{CAL}	Change in output voltage due to electrical calibration shunt
m	Transducer sensitivity (linear calibration slope)
C_1, C_2, K, M	Specified calibration constants
$\left(\frac{\Delta R}{R}\right)_{CAL}$	Unit change in sensor or transducer bridge arm resistance due to shunt calibration
R_{CAL}	Bridge arm precision shunt resistor
R_L	Sensor lead wire resistance
$\left(\frac{\Delta RG}{RG}\right)$	Unit change in strain sensor resistance
$\frac{\Delta L}{L} = \varepsilon$	Unit change in elongation (strain)
GF	Strain gage sensitivity
δ	Deflection (milli-inches)

LIST OF SYMBOLS & ABBREVIATIONS (Continued)

ε	Strain (Micro-inches per inch)
γ	Shear strain (micro-radians per radian)
σ	Normal stress psi
τ	Shear stress psi
μ	Poisson's ratio
ϕ	Principal stress direction location angle

I. INTRODUCTION:

The Fairchild Republic Company (FRC) A-10 aircraft was subjected to a complete static structural test program covering all the critical flight, landing and ground handling conditions. There were 79 separate test conditions in this test program. Four of these conditions were selected to be run as failing load tests at the conclusion of the test program. A list of the test conditions is in Table 2.

There were no major structural failures of the primary structure. There were some failures and design deficiencies in secondary structure. These failures and deficiencies are discussed in Section VII.

II. TEST ARTICLE CONFIGURATION

2.1 Aircraft Description

The A-10 is a twin engine, low wing close air support weapon system. The armament consists of a fuselage mounted GAU-8/A gun and a wide variety of external stores carried on 11 wing mounted pylons. The general arrangement is as shown in Figure 1.

The basic philosophy utilized in the design of the structure was to establish separated redundant load paths and separate elements within load paths in order to provide high residual strength after it has sustained battle damage, and long safe unrepaired service life in the presence of flaws and cracks. A general representation of the structure is shown in Fig. 2.

The fuselage is basically a four longeron system with auxiliary longerons and skin splices to meet the residual strength required for battle damage. Each of the primary tension longerons is made of three separate elements that provide residual strength to 125 percent limit load in the event of failure of any one element through fatigue cracking.

The fuselage is fabricated in three basic components. The forward section, which extends from Fuselage Station 130 to F. S. 365, contains the titanium integral armor cockpit and provides support for the in-flight refueling system (UARRSI), the GUA-8/A gun and ammunition drum, the nose landing gear and electrical equipment The mid fuselage-F. S. 365 to F. S. 524.30-functions as a container for the self-sealing fuel tanks and provides the wing attachment structure at F. S. 407.15 and 451.94. A trough for controls, electrical wiring and ducts extends the entire length of this section on each side at the 3 and 9 o'clock positions. The aft fuselage section-F. S. 524.30 to F. S. 761 provides the nacelle support structure at F. S. 541.222 and F. S. 590.109 and the empennage support structure at F. S. 688.947 and F. S. 719.908 and contains the auxiliary power unit and environmental control system.

The nacelle is initially fabricated in three basic sections - the leading edge, the center section, which houses the engine and provides the structural support of the engine and transmits the loads to the fuselage, and the aft section.

The empennage consists of the horizontal stabilizer, the elevators, the fins and the rudders.

The horizontal stabilizer is fabricated as a continuous element from tip to tip, is constant in planform and thickness and is composed of a three spar box beam with stringer stiffened (5 each) upper and lower covers - the fins, elevators, and the removable leading edge assemblies are attached to this box.

The elevators are of two spar construction with the skin panels stabilized by bonded fiber glass honeycomb core reinforcement in the area of the trailing edge. The elevators are attached to the horizontal stabilizer by hinge fittings at Buttock Lines 11.40, 53.15 and 93.40.

The fins, which are mounted on the outer extremities of the horizontal stabilizer, are also of three-spar construction. The metal skin covers between spars are stiffened by means of a single extruded element between each spar. The nose box skin is reinforced by bonded honeycomb panels.

The rudders are of single spar construction with a metal nose box and a bonded fiberglass aft section. The rudders are mounted on the fins by means of three hinge fittings.

The wing is manufactured in three sections - the center section, which is of constant section, extending from W.S. 110 left to W.S. 110 right and two outer panels. The outer panels are tapered in planform and have 7° of dihedral.

The wing structure consists of three spars and stiffened covers. The covers are separate integral planks between spars in the center section and a one piece skin panel with separate stiffeners in the outer panels. The spars are located at 13 percent, 35.5 percent and 58 percent of the wing chord with the rear spar, which is located at F.S. 463.3, being a straight line in the planform from tip to tip.

The flaps, which are of two-spar light metal construction with a bonded trailing edge, are attached at the wing trailing edge ribs. The centerline of the inboard flap track rollers are at W.S. 38.71 and 108.75, while the outboard flap rollers are at OTEFS 3.962 and OTEFS 85.204. The decelerons are mounted to the wing by hinge brackets at W.S. 230 and 287. The structure of the deceleron consists primarily of forged parts which form the nose box and front spar to which the speed brakes are attached. The speed brakes are foam filled metal skin panels.

The landing gears are of conventional construction and utilize forged alloy steel and aluminum as the primary load carrying members. The landing gears were static tested by the manufacturer (Menasco of Canada). Test fixtures which incorporated an actual upper cylinder with dummy piston were provided by Fairchild Republic Company as a means to introduce landing gear loads into the basic airframe.

A more complete structural description of the airframe is contained in SA160R9405, A-10 Structural Description Report.

2.2 Essential Differences - Static and Production Airframes

The static test article was structurally complete and was representative of the production airplane, using Aircraft No. 7 as a baseline, except for the essential differences noted in Table 1.

TABLE 1

ESSENTIAL DIFFERENCES

STATIC AND PRODUCTION AIRFRAMES

Part Number	Description	Difference
160D114008	Beam Centerline F.S. 268-365	Al. hand forging
160D115005-1	Ammo Access Door Instl.	Production changes. Static door satisfactory.
160D116004-11	Gun Fwd Supt Fitting	Al. hand forging
160D116008-11	Fitting - Gun Drive	Al. hand forging
160D116053-11, -12	Windshield Supt. Fitting	Al. hand forging
160D117110-1	Glass Assy-Windshield Flat	One layer structural glass vs. 2 layers plus an interlayer.
160D117219-11	Canopy Actuator Supt Assy.	Al. bar vs. forging
160D117242-11,-12	Hinge Canopy Fitting	Al. hand forging
160D112010-1	Former Instl FS 278 & 352.19 L.H. & R.H.	Formers changed. Strap added to production A/C. Part adequate for static.
160D216002-13, -14	F.S. 468.50 Frame	Al. hand forging
160D313002-1, -2	Longeron Istal. FS 541.222 to 688.947 lower	Continuous vs spliced longerons F.S. 633.68
160D316004-21	Aft stabilizer support	Small dimensional differences
160D316007-21	Jack Pad F.S. 590.109 Fitting Assembly	Al. hand forging
160D511403-3, -5	Fin upper and lower hinge Fitting Assy.	Design changed for fatigue. Parts adequate for Static A/C.
160D512000-1, -3	Rudder Assy - Vertical Stabilizer Empennage	Different hinge assemblies
160D514114-5, -6	T.E. Horizontal Stabilizer Panel Assy.	Inserts in honeycomb core in production A/C. Not required for Static A/C.
160D611107-3, -4	Flap Track Instl. Inbd. BL 28 & 38	Different ribs. Supports omitted from Static A/C.
160D611201-11	Skin upper Skin Assy Fwd W.S. 110-110	Two holes with different centers. Part satisfactory for Static A/C.

TABLE 1

ESSENTIAL DIFFERENCES

STATIC AND PRODUCTION AIRFRAMES
(continued)

Part Number	Description	Difference
160D611310-15	Door Center Spar	Al. alloy plate in Static A/C. Forging in Production A/C.
160D611319-11	Cap - Lower Front Spar	Dimensional Increase for Production Part. -11 adequate for Static A/C.
160D611321-11	Center Lower Spar Cap W.S. 110	Two holes in Static A/C with different centers. Part satisfactory for Static A/C.
160D611625-13, -14	Landing Gear Backup Fitting W.S. 110	Al. hand forging
160D611626-13, -14	Landing Gear Backup Fitting W.S. 110	Al. hand forging
160D611634-15, -16	Fitting - Flap Actuator	Al. hand forging
160D612402-37, -38, -39, -40	Rib Instl -Front to rear Spar W.S. 143.75	Variations in joggle dimensions in ribs. Ribs satisfactory for Static A/C.
160D612511-3, -4	T.E. Instl, Outbd. Wing Panel W. S. 110-195	Channel Assy reworked to 160H612511 to allow loading of Static A/C.
160D612602-15, -16 -27, -28	Fitting Aft - Outbd. Wing Panel	Dimensional variations in widths and lengths of pylon fittings.
160D624500	Flap Drive Instl. - Wing Trailing Edge 20°	Flap travel for Production A/C, limited to 20°. Static A/C adequate.
160D955307-1	Bracket F.S. 405 Frame Installation	Part omitted on Production A/C. Already on Static A/C.
Yaw Control System		
160D123216	Stop	Replaced by MS20392-4C57 Pin in 160D123171-38-4 which replaces 160D123171-18-2
160D123210	Crank, Crossover	Replaced by 160D123151 which replaces 160D123150
160C123005	Pushrod	Replaced by 160C123003
160D123140-18-2	Brake Crank Arm Upper	Replaced by 160D123140-3 & -4
160D123002-1	Brake Rod	Replaced by 160D123002-5

III. TEST CONDITIONS

All parts of the structure, including carrythrough structure, were loaded during the static test program. Noncritical parts whose loading had no significant influence on critical parts were not tested. In each test condition, all parts were loaded simultaneously in such a manner as to apply the critical design external loads to the entire structure or the local area of concern. Table 2 contains a list of the static airframe balanced aircraft and component test conditions. Detailed test loads for these conditions are presented in the references.

TABLE 2

BALANCED AIRPLANE TEST

Condition	Critical Element	Comment
1. PB-BDW/MFCG-750-05 (7.33g) (Ref. 1)	Fuselage upper, lower longerons; inner midspar web, wing upper inboard covers, upper skin 110; horizontal tail total load.	Condition comes closest to loading all primary components to critical load at same time.
2. RPM/RPDM-BDW-750-05 (5.86/3.0g) (Ref. 1)	Wing inboard rear spar web; fuselage forward and aft longerons, fuselage torsion; vertical fin mid and rear spars, stabilizer, and flaps in the retracted position.	5.86g empennage loading adjusted to reproduce critical fin load of 3.0g condition.
3. PB-MTW-372-00 (5.0g) (Ref. 2)	Wing mid spar upper cap; rear spar web 110, front and mid spar upper outboard caps, front spar upper inboard cap.	Critical for wing inboard and outboard upper covers.
4. NB-BDW-268-00 (-3.0g) (Ref. 7)	Fuselage aft longerons.	Only condition which produces compression in upper aft fuselage.
5. NB-MTW/BDW-605-00 (-2.0g/-3.0g) (Ref. 7)	Wing inboard FS web; lower FS cap, web; lower outboard skins wing-fuselage fittings.	Combines MTW loads for wing and BDW loads for fuselage.
6. RPM-BDW-750-05 (5.86g) (Ref. 1)	Empennage and aft fuselage.	Replaces the original RPM condition as the critical empennage test condition.

TABLE 2

COMPONENTS TESTS

Condition

1. Nacelle Component Test (Ref. 2 & 6)

   a. PDY-BDW-600-20 (7.33g)

   b. R-BDW-680-20 (-1.0g)

2. Empennage (Ref. 8 & 3)

   a. Empennage component test

      SSRR/OSMR-MFCG-363-00 (1.0g)

   b. Elevator component test

      PDY-MFCG-378-00 (4.5g)

3. Deceleron Component Test (Ref. 9)

   a. 360 KTS, δ_A = 19°

      δ_{SB} = 50%

   b. 360 KTS, δ_A = 20°

      δ_{SB} = 50%

   c. 280 KTS, δ_A = -21°

      δ_{SB} = 80%

   d. 450 KTS, δ_A = 28°

      δ_{SB} = 0%

4. Flaps (Ref. 10)

   200 KTS, δ_F = 20°

   PB-MTW-302-00 (3.33g)

5. Nose Gear Door, and Uplock (Ref. 4)

   450 KTS, 7.33g

TABLE 2

COMPONENTS TESTS
(continued)

6. Nose Landing Gear Supports (Ref. 12)

   a. Forward Tow

   b. Aft Tow

   c. Unsymmetrical brake right gear

   d. Unsymmetrical brake left gear

7. Main Gear Doors and Uplock (Ref. 4)

   450 KTS, 5.86g Roll

8. Main Landing Gear Supports (Ref. 12)

   a. Two point braked roll

   b. Reverse brake

   c. Right turn no brakes

   d. Right turn symmetrical brake

   e. Unsymmetrical brake left gear

9. Slat (Ref. 5)

   M = .38, sea level, slat extended

10. Pylons (Ref. 13)

   BL 0

   a. 6 CBU 58/MER, (3-3 Config.)

      4.0g R.P., 100°sec. ($-\beta, +n_x$)

   b. 4 CBU 58/MER, (3-1 Config.),

      4.0g R.P., 100°/sec. ($-\beta, +n_x$)

   c. 4 MK 82/MER, (3-1 Config.)

      4.0g R.P., 210°/sec. ($-\beta, -n_x$)

   d. 6 CBU 58/MER (3-3 Config.),

      4.0g R.P., 100°/sec. R.R.

      ($+\beta, -n_x$)

TABLE 2

COMPONENTS TESTS
(continued)

BL 23

e. 6 MK 82/MER, (3-3 Config.)
4.0g R.P., 210°/sec. R.R.,
$(-\beta,+\eta_x)$

f. 4 MK 82/MER, (3-1 Config.)
4.0g R.P., 210°/sec. R.R.
$(-\beta,-\eta_x)$

BL 66

g. 600 Gal. full tank, 4.0g R.P.,
100°/sec. R.R. $(-\beta,+\eta_x)$

h. 600 Gal. partial fuel 4.0g R.P.,
100°/sec. R.R. $(-\beta,+\eta_x)$

BL 144

i. 1 MK-84 TVGB, 5.86g R.R.,
120°/sec. R.R. $(+\beta,+\eta_x)$

j. 3 CBU 58/TER, 4.0g R.P.,
110°/sec. R.R. $(+\beta,-\eta_x)$

k. MK-84 TVGB, 5.86g R.P.,
120°/sec. R.R. $(+\beta,-\eta_x)$

l. MK-84 TVGB, 5.86g R.P.,
120°/sec. R.R. $(-\beta,-\eta_x)$

BL 187

m. 1 BLU-27 B/B (U/F) 5.86g R.P.,
170°/sec. R.R. $(+\beta,-\eta_x)$

n. 1 SUU-51, 5.86g R.P.,
165°/sec. R.R. $(-\beta,+\eta_x)$

TABLE 2

COMPONENTS TESTS
(continued)

BL 230

o. 1 SUU-51, 5.86g R.P.,

160°/sec. R.R. ($+\beta, -\eta_x$)

p. 1 QRC-559 (U/F), 5.86g R.P.

160°/sec. R.R. ($+\beta, -\eta_x$)

11. Ammunition Drum Support (Ref. 18)

a. Arrested Landing - Max. Fwd. Load

b. Arrested Landing - Max. Vert. Upward Load

12. Gun Mounts

No Static Test Required

13. Canopy, Windshield Cockpit Tests (Ref. 11)

a. Canopy Open - 27.5°, 70 knot side wind

b. Canopy Open - 27.5°, 70 knot head wind

c. 7.35 psi (Ultimate) Cockpit Pressurization

14. Jack, Hoist Points (Ref. 19)

a. Max. Aircraft Sling Cable Load - Fwd. Fuselage

b. Forward Fuselage Jack, Vertical + Outboard Load

c. Forward Fuselage Jack, Vertical + Forward Load

d. Aft Fuselage Jack, Vertical + Side Load

e. Aft Fuselage Jack, Vertical + Aft Load

f. Wing Jack, Vertical + Outboard Load

g. Wing Jack, Vertical + Forward Load

15. Primary Flight Control Systems (Ref. 14)

a. Aileron Upfloat 150# Left, Right on Stick

b. Stops, 150# Left, Right on Stick

c. Jam at Left Elevator Horn, 375# Aft on Stick

d. Jam at Left Elevator Horn, 375# Forward on Stick

TABLE 2

COMPONENTS TESTS
(continued)

Condition

e. Stops, 375# Aft and Forward on Stick

f. Jam at Right Rudder Horn, 450# Left Rudder Pedal

g. Jam at Right Rudder Horn, 450# Right Rudder Pedal

h. Overtravel Right, 450# Both Rudder Pedals

i. Stops, Right Pedal on Stop, 450# Right Pedal

j. Brake Pedals Neutral, 450# Both Pedals

k. Brake Pedals Fully Depressed, 450# Left Pedal

16. Air Fueling Receptacle (Ref. 17)

a. Boom Impact with Side Load I

b. Boom Impact II

c. Tension with Side Load III

d. Tension IV

e. Boom Impact, Fuselage Skin V

17. Landing Gear Pod (Ref. 21)

Combined High Speed with Slip

18. Nacelle Doors Open (Ref. 16)

70 knot side wind

19. Operation of Control Surfaces (Ref. 20)

a. Roll

b. Pitch

c. Yaw

20. Pave Penny Pod (Ref. 18)

Rudder Kick, M=75 at 5000 ft.

TABLE 2

COMPONENTS TESTS
(continued)

21. Aileron Tab (Ref. 15)

400 Knot, Manual Mode $\delta_{ail} = -21°, \delta_{SB} = 0°, \delta_{TAB} = 45°$

22. Seat Support Structure (Ref. 25)

40g Forward Crash

IV. TEST METHODS

1. Floating Test Set-up and Procedures

A floating test set-up was used for the A-10 static test. With this procedure, the entire airframe was tested as one integral unit, with its weight and the weight of all the attached test fixtures counterbalanced in such a way that the airframe was suspended with no fixed jig attachments.

Counterbalancing was accomplished by attaching steel cables to adhesive bonded tension patches and associated whiffle trees on the structure and to other structural loading fixtures and aircraft hard points. The cables were attached to hydraulic jacks which were on a hydraulic system completely independent of the test load hydraulic system. When the dead weight jacks were pressurized, the entire test article and whiffle tree weight were counterbalanced. With the aircraft in an essentially zero "g" condition, an excellent visual indication of any unbalanced loadings resulted because the aircraft would respond to these unbalanced loads by pitching, rolling, yawing or translating in the jig.

2. Load Introduction

Static test loads were applied to the structure through a mechanical system of linkage called "whiffle trees". It was possible to connect any number of load points, but for any given situation there was an optimum arrangement. The arrangement for any one condition was determined by the basic structure and its associated deflections, the limitations imposed by whiffle tree dimensions, and external jig clearances. This linkage system was located between the test structure and hydraulic load jack. The first attachment was made to a mechanical load fastener in or on the basic test structure, a bonded or riveted shear strap, a bonded tension

load patch, compression pad, or any attachment that was designed to meet a specific problem. The linkage was attached with flexible cable connectors. For flexible cable connection, a special quick-disconnect fitting was used with a selection of several flexible cable lengths. Figures 3 & 4 show typical test set-ups.

3. Dummy or Simulated Aircraft Components

The loading of certain non-airframe components was necessary to properly introduce and distribute loads to the aircraft structure. These components were designed and fabricated by Fairchild Republic Company to be interchangeable with the equipment they replaced. Load application points were part of these components. In the case of the A-10, these dummy components or fixtures included the engines, Auxiliary Power Unit (APU), environmental control system, GAU-8/A gun and ammunition drum, aerial refueling receptacle (UARRSI), and landing gear. A complete list is given in Table No. 3.

TABLE 3 DUMMY TEST FIXTURES

FRC DWG NO.	DESCRIPTION
GT160KG010	Engine Installation - Simulated
GT160KG011	Ammunition Drum Loading Fixture
GT160KG013	Landing Gear Loading Static Test Fixture, Main Gear
GT160KG014	Landing Gear Loading Static Test Fixture, Nose Gear
GT160KG015	Gun Loading Fixture, Static Airplane
GT160KG016	UARRSI Loading Fixture
GT160KG017	Primary APU and Inner Cooler, Static Airplane
GT160KG018	Pylon Test Fixture, Wing Station 23.00, Static Test
GT160KG019	Pylon Test Fixture, Body Line 66.00, Static Test
GT160KG021	Cockpit Pressure Seals
GT160KG022	Hydraulic Installation, A-10A Static Test Aircraft

4. Hydraulic System

The hydraulic system for the A-10 Static Test Program consisted of the following elements: (Figure No. 5)

a. Hydraulic Power Supply

b. Shut-off Valves

c. Dump Valve

d. Edison Hydraulic Load Maintainer

e. Hydraulic Cylinders

4.1 Hydraulic Power Supply

Hydraulic pressure for the A-10 Static Test was taken from a 1-1/2" supply line which runs the full length of the test floor in a small trench. Manifolded to this line in an insulated enclosure are two 35 GPM and one 50 GPM, 5000 psi, variable displacement, pressure compensated hydraulic pump units. The pumps were operated at 3000 psi during A-10 testing.

4.2 Shut-Off Valves

All shut-off valves were fast-acting ball valves. Three valves were provided as follows:

(1) Shut-off for the manifold and control valves for picking up dead weight baskets.

(2) Shut-off for the manifold and control valves for moving the aircraft control surfaces.

(3) Shut-off for the Edison Hydraulic Load Maintainer.

4.3 Dump Valve

One manual, lever-actuated thru-way dump valve was provided at the master Edison Cabinet. Operation of this valve closed off supply pressure to the Edisons and allowed all channels under load to simultaneously and rapidly bleed off.

4.4 Edison Hydraulic Load Maintainer

The Edison Hydraulic Load Maintainer is capable of receiving a constant hydraulic pressure supply and redistributing it to ten separate outlet channels in such a manner that each channel can have its own specified pressure. The Edison allows all ten pressures to be increased or decreased simultaneously and in exactly the same ratio. Each pressure channel is self-regulating and automatically adjusts to load demand. Any number of Edisons may be coupled together to simultaneously control as many channels as needed.

A manual quick-dump valve was added to the Load Maintainer which, when operated, shuts off supply pressure to the Maintainer and permits a sudden reversal of flow from all hydraulic cylinders under load.

4.5 Hydraulic Cylinders

The hydraulic cylinders used for the A-10 Static Test are limited to 1,500 psi and 2,000 psi maximum operating pressure depending on their particular size. All cylinders were overhauled prior to being installed on the A-10 test set-up.

5. Loads

The loads were derived from analytic (predicted) shear, bending moment and torque curves supplied by Fairchild Republic Company. These curves depicted various flight conditions for the wing, fuselage and empennage. The values of the above were plotted versus station locations in inches for each component.

The structure was tested to the most critical conditions; that is, conditions where the loads are so high in a particular area of the structure as to be considered critical, based on the maximum external loads and internal loads analyses.

The loading was extracted from the shear curves and converted to a series of uniformly distributed loads and concentrated loads. The loads, when multiplied by the moment or torque arm provided moment and torque values versus station that matched the analytic moment and torque curves.

A final check of the loading for the complete structure was made to assure that the loading was balanced, i.e., total up load equals total down load and all moments are balanced.

Detailed test loads are presented in References 1 through 21.

V. TEST PROCEDURES

1. Load Application

For each test condition the loads were applied in 10% of Design Ultimate Load (DUL) increments up to Design Limit Load (DLL). The loads were then reduced to 30% DUL and held at this level while the previously recorded stresses, loads and deflections were checked. After the check was completed, the loads were again increased incrementally up to 100% DUL. The loads were then reduced incrementally to zero load. Loads were controlled using an Edison Hydraulic Load Maintainer (reference paragraph 4.4). The test cabinet operator applied loads only upon direct command of the test director. The manual quick-dump valve (reference paragraph 4.4) was operated by the test cabinet operator. The dump valve was actuated only upon direct command of the test director (Figure 6).

2. Data Recording

Data was recorded on demand at each of the load increments up through 80% DUL. From 80% DUL to 100% DUL and back to 75% DUL, the data were recorded continuously at a preset sampling rate

(e.g., one sample per second). Data was recorded on demand from 66.7% DUL back to zero load. The use of on-line, real-time monitoring of strain gages, deflections and load cells was utilized to insure the safety of the test article. A more detailed explanation of these procedures can be found in Sections V and VII. At each load increment, selected data channels were monitored by the test engineer and instrumentation engineer. Any deviation from predicted values was analyzed by the AFFDL/FBT and Fairchild Republic Company engineers before proceeding with the test. Data acquisition was accomplished as noted in Sections V and VI. The rapid availability of data permitted timely decisions by the test engineer as to go or no-go at any point in a test.

3. Protection of Test Article

Integrity of the test article was of prime concern throughout the test program. Overloads for a full floating test such as this would only be expected from three sources - incorrect Edison Hydraulic Load Maintainer settings, incorrect test loads derivation or secondary load redistribution after a primary structural failure, or a test jig failure. Should the first two situations occur, the error would be discovered almost immediately at very low load levels because of abnormal movement of the test article in the jig. The test procedure was to stop the test and recheck all Edison settings. This, however, is normally a final backup safety. Primary safety was provided by checking of all loads prior to test. All test loads derived by the test engineer were detail checked by a second engineer and an on-site Fairchild Republic Company engineer. Detailed records and worksheets were maintained throughout the check procedure. The Edison units had a checksheet placed upon them for

each test condition. The hydraulic worker who initially set up the required pressure and the test engineer who checked it both signed this checksheet. These procedures normally precluded errors. The third situation, jig or structural failure inducing excessive redistributed load, is not predictable, but protection was generally achieved by the load relief as the aircraft moves in the jig due to the unbalance produced. Test hardware was double checked similarly to items noted above. The aluminum whiffle trees have a slow mode of failure which acts as a damper in the case of overload. To the greatest extent practicable, these whiffle trees were loaded to allowables suitable to produce this effect.

Failure modes for the Edison Maintainers were studied in detail and all known modes either reduced the load or held it at a constant setting. It is theoretically possible for a large piece of dirt to jam an Edison valve in the open pressure position. To preclude this, the A-10 hydraulic supply was filtered and the Edison valves had relatively wide fit dimensions. These facts would seem to eliminate the possibility of this type of failure. However, if such a failure should occur, once again the forgiving floating set-up should permit a total system dump before any damage could occur.

VI. INSTRUMENTATION

1. General

The data acquisition portion of this test program was designed to fulfill two requirements: (1) to accurately measure and monitor the aerodynamic and inertia loads applied to the airframe in order to insure proper environmental simulation and (2) to continuously monitor the response of the structure to these applied stimuli.

Successful implementation of the above was required to prevent undesirable catastrophic failures; to provide a basis for the measurement and analysis of applied stresses and deflections for comparison with theoretical predictions; and to document a complete set of structural response data for future utilization.

2. Transducer and Measurement Parameters

2.1 Load Cells

Approximately 50 strain-gage-based force sensitive transducers were used for load monitoring. These were commercial units, in ranges from 2,000 pounds to 50,000 pounds. Specifications include: 350 ohm bridge impedance, 3 millivolt per volt full-scale sensitivity, 15 volts input and 0.1% full-scale linearity. The load cells are calibrated in-house against PME certified secondary standard units. The automatically recorded calibration data are computer-processed utilizing a linear regression analysis to obtain the best fit slope, or sensitivity, of the unit in terms of pounds per microvolt output (m). This end-to-end calibration is standardized by means of an electrical shunt calibration across one bridge arm, resulting in a differential low level output $(E_{cal})_{cal}$. Standardization is achieved at test time by repeating and recording the electrical shunt calibration procedure using the same type of signal conditioning equipment, cabling and shunt resistor values. The resulting differential low level output is defined as (E_{cal}) test. Thus, for any incremental load cell voltage output E_o, the load computation is:

$$LB = \frac{(E_{cal})_{cal} \times m \times E_o}{(E_{cal})\ \text{test}} \quad \text{or} \quad LB = M \times \frac{E_o}{(E_{cal})\ \text{test}}$$

2.2 Strain Gages

Approximately 240 rosette locations and 650 axial locations were installed for a total of 1370 strain channels to be monitored for various conditions. Note: Sensor locations are provided in Fairchild Republic Company Document 160K995247A. These electrical strain sensors were of Constantan foil construction in an encapsulating polyimide carrier and were bonded to the structure utilizing a two-part epoxy adhesive. The gages had an electrical resistance of 350 ohms, a nominal strain sensitivity of 2.08 and were all utilized as single-active-arm elements in Wheatstone Bridge configurations. (The adverse effects of localized wrinkling or buckling on the outputs of strain gage rosettes located on unstiffened panels were eliminated, where possible, by the use of backed-up sensors. In this application, each rosette gage arm and its corresponding back-up gage were connected in series in the active bridge arm. This averaging technique effectively eliminated the undesirable effects of localized buckling in the gage area.) The three-element strain rosettes were of the flat type, with a rectangular geometry. All strain gages were of the self-temperature-compensating type, for elimination of apparent strain indications resulting from possible thermal expansion of the test item.

For a constant voltage input (V), single active arm bridge network, with high impedance output resistance, the output voltage change may be expressed as $\Delta E = \frac{V}{4} \frac{\Delta R_G}{R_G}$, where $\frac{\Delta R_G}{R_G}$ represents the change in strain gage resistance; therefore,

$\frac{\Delta R_G}{R_G} = \frac{4 \Delta E}{V}$. By definition, the strain gage sensitivity or gage factor (GF) is supplied for each lot number of gages as unit change in gage resistance divided by unit change in elongation over the bond strain-sensitive or

active length of the gage:

$$GF = \frac{\Delta R_G}{R_G} \div \frac{\Delta L}{L}. \quad \text{Therefore strain} = \frac{\Delta L}{L} = \frac{4\Delta E}{V \times GF}.$$

In a method similar to that used for standardizing load cell outputs, and to avoid the necessity for measuring bridge voltage V, an electrical shunt calibration of the active bridge arm (strain gage) is performed. This results in a unique strain gage channel output:

$$\Delta E_{cal} = \frac{V}{4} \left(\frac{\Delta R}{R}\right)_{cal}, \text{ where } \left(\frac{\Delta R}{R}\right)_{cal} \text{ is made to be } \frac{R_G}{R_G + R_{cal}}.$$

By substituting above, the expression for measured strain output then becomes:

$$\text{Strain } (\varepsilon) = \frac{1}{GF} \times \frac{R_G}{R_G + R_{cal}} \times \frac{\Delta E}{\Delta E_{cal}}.$$

This simplified procedure does not compensate for bridge non-linearity (a second order effect), parasitic lead wire resistance error, or strain gage transverse sensitivity. Analysis shows that the lead resistance (R_L) error can be corrected for by modifying the resistance portion of the equation to

$$\frac{(R_G + R_L)^2}{R_G\,(R_G + R_{cal} + R_L)}$$

For specified values of resistance and strain sensitivity, the equation becomes of the form $\varepsilon = M \left(\frac{\Delta\varepsilon}{\Delta\varepsilon cal}\right)$.

For the 650 single gage locations, the one dimensional stress in the gage axial direction is merely $E \times \varepsilon$ where E is the elastic modulus of the structural material. In case of the 240 rosette locations, the individual leg strains (ε_A, ε_B, ε_C) are computed as above, and the principal strains calculated:

$$\varepsilon_{max} = \frac{1}{2}(\varepsilon_A + \varepsilon_C) + \frac{1}{2}\left[\gamma_{AC}^2 + (\varepsilon_A - \varepsilon_C)^2\right]^{\frac{1}{2}}$$

$$\varepsilon_{min} = \frac{1}{2}(\varepsilon_A + \varepsilon_C) - \frac{1}{2}\left[\gamma_{AC}^2 + (\varepsilon_A - \varepsilon_C)^2\right]^{\frac{1}{2}}$$

$$\gamma_{max} + \left[(\varepsilon_A - \varepsilon_C)^2 + \gamma_{AC}^2\right]^{\frac{1}{2}}$$

$$\phi = \frac{1}{2}\tan^{-1}\frac{\gamma AC}{\varepsilon_A - \varepsilon_C}$$

where $\gamma_{AC} = 2\varepsilon_B - \varepsilon_A - \varepsilon_C$.

Final results are then presented in terms of principal stress:

$$\sigma_{max} = \frac{E}{1-\mu^2}(\varepsilon_{max} + \mu\varepsilon_{min})$$

$$\sigma_{min} = \frac{E}{1-\mu^2}(\varepsilon_{min} + \mu\varepsilon_{max})$$

$$\tau_{max} = \frac{1}{2}(\sigma_{max} - \sigma_{min})$$

2.3 Electrical Deflection Indicators (EDI). These commercially available transducers are basically 1000 ohm wire-wound multiple-turn potentiometers. Units available for this test range from 1/2 inch full scale to 10 feet full scale. Linearity and resolution vary with size; 0.1 percent to 0.35 percent for the former and 0.001 inch to 0.041 inch for the latter. Nominal output is 10 VDC, with negator-type springs maintaining a constant static tension of 15 to 20 ounces on the attachment cable. A maximum of 50 units were provided for use per test condition. Deflections in milli-inches are computed for each channel using an equation of the form:

$$\delta = \Delta E \times m \times \frac{(C_1 + C_2)\text{ Cal}}{(C_1 + C_2)\text{ Test}} - \frac{K \times \Delta E}{(C_1 + C_2)\text{ Test}}$$

where m is the slope of the calibration curve in milli-inches per micro volt, and C_1, C_2 and K are calibration constants.

EDI raw deflection data was corrected for effects of roll, pitch and yaw, as well as vertical and horizontal translation, by referencing six correction EDI units which were mounted to the airframe in such a manner as to be insensitive to elastic deflections.

The procedures discussed above for measuring load, strain and deflection are congenerous in nature, in that bridge supply voltages and system gain sensitivities do not enter into the computations, the only requirement being that transducer supply voltages and system offset and gain sensitivity not change during the course of the test. This procedure greatly simplifies operations, since exact transducer supply voltages, for example, need not be set or measured. The above parameters are of course important for optimum transducer output and scaling purposes.

VII. DATA ACQUISITION AND PROCESSING

1. Digital Data Acquisition Components

The heart of the system was four 128 channel, in-house modified, Real-Time Peripheral (RTP) units, controlled by a DEC PDP-11/40 minicomputer. Sampled data was fed to a CDC 1604B digital computer for raw data collection, magnetic tape storage, and on-line processing for displays. (See Fig. 7).

The A-10 digital data acquisition system modular size was based on the maximum number of 128 channel RTP units that can be fed to the four input ports of the PDP-11/40 minicomputer; hence 512 total channels. With prudent acceptance of a worst-case condition of three bad channels per unit, 500 channels per test condition were provided. Within this framework, signal conditioning was provided for 50 load cells, 50 EDI and up to 450 strain gages, with the provision that total number of

measurements not exceed the 512 channel system capacity. This allowed a capability for reducing the total number of load and deflection measurements in favor of additional strain measurements.

Strain gage monitoring provides a convenient example of a data system component utilization and performance. The strain gage instrumentation, installed by the contractor in accordance with FBT instructions, terminated in spade-lug-fitted cables extending approximately 50 feet from the structure. These cables were routed as conveniently as possible to a centralized strain gage interface panel area, which is the starting point for the portable or remote components of the FBT digital data acquisition system.

The strain gage interface provided 450 individual terminals for installation of bridge completion resistors and appropriate jumpers (all strain gage bridges are single active arm). This is an important area, for at this point the 400 to 450 strain gages to be monitored and recorded for a particular test were selected from the 1300 available sensor cables and hand-wired into the appropriate system channel. Strain gage requirements varied with test conditions. This procedure required both hardware and software manipulation, since scale factors, conversion constants and channel/sensor identifiers varied with test conditions. The idealized alternative to this procedure, to enable permanent hard-wiring of approximately 1400 channels with no changes required, would have utilized approximately 90% of FBT available data system components.

The strain gage half-bridges thus formed at the interface panels were carried by 450 six conductor, double-shielded 50 foot cables to nine, 50 channel signal conditioning cabinets. These units were of the constant voltage, common power supply type, and provided for individual

excitation level adjustment, initial bridge balancing and shunt calibration. Short, two conductor output cables then carried the conditioned low level signal to the four RTP units mentioned above.

The RTP units, with in-house modified logic circuits compatible with the PDP-11/40 minicomputer, accept, amplify, commutate and convert the 128 input signals. Bi-polar inputs, up to a maximum level of 100 milli-volts, are time-shared by means of individual electro-mechanical switch cartridges into eight fixed gain instrumentation amplifiers (16 channels per amplifier). These high-level outputs are commutated into a 14 bit analog to digital converter. The units are scaled to provide 8000 counts digital output for 100 milli-volts analog input, resulting in a resolution of 12.5 micro-volts per count. These units operate at a fixed rate of 5 samples per channel per second, thus a complete data scan can be achieved in 200 milli-seconds. Actual data sampling rate for any given test, however, is computer-controlled. The outputs of two of the four RTP's (256 channels) can be processed into engineering units and displayed in an on-line, real-time manner during the test.

The PDP-11/40 minicomputer, remotely located from the test area, controls the operation of the RTP units through a four-port direct memory access channel (DMA). By taking one 200 milli-second data scan from each of the four units in sequence, one set or block of data can be obtained from 512 sensors in less than one second.

The data blocks thus obtained are immediately passed on to the CDC 1604B digital computer, where the raw data from 512 channels is recorded on magnetic tape for off-line processing, and the output of half the channels is processed into usable engineering parameters for on-line displays. This latter information is sent back through the PDP-11, which

controls two on-line display devices located on the test floor. Due to the large amount of continuous processing and scanning involved in the automatic exceedance monitoring portion of the program (described below), the effective data sampling rate for recording purposes was approximately one block every second in the automatic sampling mode. On-line data displays and computer-controlled exceedance monitoring were also automatically up-dated at this same rate.

On-line display units included a Varian Model 3113 electrostatic plotter programmed to display measured stress or deflection plotted as a function of percent of applied load condition. A load, stress or deflection plot for a manually selected sensor or strain rosette, utilizing all data points recorded up to that point, could be obtained in ten to thirty seconds. The second on-line display unit was an alphanumeric CRT terminal displaying manually selected sensor outputs on demand. This unit was available to the test engineer to monitor the accuracy of the applied loads. In addition, roll, pitch and yaw were displayed in degrees, so that undesirable attitudes of the floating airframe created during load application could be minimized. This CRT terminal was also utilized as the display device for the automatic exceedance alarm portion of the program.

2. <u>Data Acquisition and Response Monitoring Procedure</u>

The digital data acquisition system performed three interrelated procedures: the logging of the test data from all channels for subsequent off-line processing, analysis and reporting; the on-line continuously up-dated display of selected channels (50%) on a manual demand basis; and automatic computer monitoring of the same channels for linearity and magnitude exceedance. Strain gage or EDI sensors

selected by FBT and FRC as "critical" were specified on a per-condition basis.

Transducer outputs at zero applied load were recorded for all channels. At the same time, an electrical shunt calibration/standardization record was obtained. This information was then used as a basis for computing loads, stresses and deflections throughout the test. After all loads were adjusted, stabilized and verified by the on-line CRT display at 10 percent DUL, several blocks of data were manually recorded. This same procedure was repeated at 20%, 30%, 40% and 50%. Using the data recorded at these five load increments, the computer would then apply a linear fit to the outputs generated by the specified critical strain and deflection sensors. This line was continually extrapolated as the test progressed. For all critical data recorded at ensuing higher load levels (60%, 70%, etc) the computer would compare the linearly extrapolated value with the actual value at that time. A plus or minus deviation of 5% would enable a linearity exceedance alarm display on the CRT terminal. In addition, if the linear fit of the 10% through 50% data extrapolated to a stress or deflection equal to or greater than predicted or allowable value, a magnitude exceedance alarm was triggered. The alpha-numeric exceedance alarm displays were purposely limited to include only the transducer number and a decimal representation of the measured stress or deflection, as a percentage of the allowable value for that load level.

A plot of stress or deflection vs. percent load condition could be obtained at any time, for any critical channel, by using the electrostatic plotter. If the transducer of interest was a strain gage

rosette, a plot of maximum and minimum normal stress, maximum shear stress, and principal stress direction was obtained by keying in the location of the "A" leg.

In addition to the procedure discussed above, the test was halted after obtaining data at 67%. Loads were reduced to 30% and held for a period of time while all data channels were processed and visually checked for computational procedure, transducer quality and structural response. It was also possible, by simulation techniques, to produce stress and deflection plots of all channels at this time.

With an affirmative decision, based on the analysis of these data, the test proceeded to higher loads, with automatic data sampling from 80% to 100%, at a one sample per second up-dating rate.

Data analysis at load plateaus above 67% was confined to critical sensor channels defined during the analysis carried out (over as long a period of time as required) after first acquiring data to 67% and returning to 30%. In addition, the exceedance alarm option was also functional, to monitor any other previously identified channels. Any of the other 250 channels were displayed on the CRT by manual selection at the terminal. Depending on the duration of load plateaus, 10" x 10" plots were made at less than ten seconds per plot, but no data logging was possible during plotting periods. Data was also recorded during unloading, with a zero check and calibration set repeated at zero load.

All test information resulting from the recorded data of the various test conditions is on file at the Structures Test Branch of the AF Flight Dynamics Laboratory (AFFDL/FBT).

SECTION VIII

TEST CONDITIONS, TEST DATES AND TEST RESULTS

The A-10 was tested for the conditions listed below:

ITEM NO	COND NO	TEST DATE	TEST CONDITION	DATA S/N	PERCENT DUL SUPPORTED
1*	A-1	6 June 75	PB-BDW/MFCG-750-05 (7.33g)	019	95%
2	C-1b	8 July 75	Nacelle Component Test	031	100%
3	C-2b	11 July 75	Elevator Component Test	041	100%
4	C-2a	22 July 75	Empennage Component Test	052	100%
5	A-3 C-1a	30 July 75	PB-MTW-372-00 (5.0g) and Nacelle Component Test	024	100%
6	C-16d	4 Aug 75	Air Refueling Receptacle Cond IV	**	100%
7	C-16c	14 Aug 75	Air Refueling Receptacle Cond III	**	100%
8	C-16a	15 Aug 75	Air Refueling Receptacle Cond I	**	100%
9	C-16b	15 Aug 75	Air Refueling Receptacle Cond II	**	100%
10	C-16e	18 Aug 75	Air Refueling Receptacle Cond V	**	100%
11	C-4	22 Aug 75	Flap Component Test	072	100%
12	C-5	26 Aug 75	Nose Gear Doors & Uplock	081	100%
13	C-9	2 Oct 75	Slat Component Test	101	100%
14	A-2	21 Oct 75	RPM/RPDM-BDW-750-05 (5.86/3.0g)	093	100%
15	A-4	31 Oct 75	NB-BDW-268-00 (-3.0g)	121	100%
16	C-7	4 Nov 75	Main Gear Doors & Uplock	112	100%
17	A-5	10 Nov 75	NB-BDW/MTW-605-00 (-3.0/-2.0g)	123	100%
18	C-7	26 Nov 75	Main Gear Torque Arm Fairing	113	100%
19	C-11a	19 Dec 75	Ammo Drum Support-Max Fwd Load	131	100%
20	C-11b	23 Dec 75	Ammo Drum Support-Max Up Load	132	100%
21	C-6c	16 Jan 76	NLG Unsymmetrical Braking-Lt Gear	141	100%
22	C-6d	16 Jan 76	NLG Unsymmetrical Braking-Rt Gear	142	100%
23	C-6b	21 Jan 76	NLG Aft Towing	143	100%
24	C-6a	23 Jan 76	NLG Forward Towing	144	100%
25	C-8a	4 Feb 76	MLG Two Point Braked Roll	151	100%
26	C-8e	6 Feb 76	MLG Unsymmetrical Braking-Lt Gear	152	100%
27	C-8c	10 Feb 76	MLG Right Turn-No Brakes	153	100%
28	C-8d	12 Feb 76	MLG Right Turn-Symmetrical Braking	154	100%
29	C-8b	17 Feb 76	MLG Reverse Braking	155	100%
30	C-15d	15 Mar 76	Pitch Control-Power Mode	183	100%

ITEM NO	COND NO	TEST DATE	TEST CONDITION	DATA S/N	PERCENT DUL SUPPORT
31	C-15e	15 Mar 76	Pitch Control-System Stop	184	100%
32	C-15c	16 Mar 76	Pitch Control-Power Mode	186	100%
33	C-15e	16 Mar 76	Pitch Control-System Stop	187	100%
34*	C-15g	6 Apr 76	Yaw Control-Power Mode, Rt Pedal	191	75%
35*	C-15f	8 Apr 76	Yaw Control-Power Mode, Lt Pedal	192	100%
36*	C-15g	9 Apr 76	Yaw Control-Power Mode, Rt Pedal	194	100%
37*	C-3a	14 Apr 76	Deceleron Component Test #1	166	100%
38*	C-15i	19 Apr 76	Yaw Control-Rt Stop	196	80%
39	C-3c	28 Apr 76	Deceleron Component Test #3	201	100%
40	C-10e	25 May 76	BL 23 Pylon-Condition #5	221	100%
41	C-10f	1 June 76	BL 23 Pylon-Condition #6	225	100%
42*	C-10g	4 June 76	BL 66 Pylon-Condition #7	232	97%
43	C-10a	11 June 76	BL 0 Pylon-Condition #1	213	100%
44	C-10d	11 June 76	BL 0 Pylon-Condition #4	214	100%
45	C-10c	15 June 76	BL 0 Pylon-Condition #3	215	100%
46	C-10b	15 June 76	BL 0 Pylon-Condition #2	216	100%
47*	C-10g	17 June 76	BL 66 Pylon-Condition #7	233	100%
48	C-10h	18 June 76	BL 66 Pylon-Condition #8	234	100%
49	C-3b	24 June 76	Deceleron Component Test #2	204	100%
50	C-10m	1 July 76	BL 187 Pylon-Condition #13	242	100%
51	C-10n	2 July 76	BL 187 Pylon-Condition #14	243	100%
52	C-10o	7 July 76	BL 230 Pylon-Condition #15	250	100%
53	C-10p	8 July 76	BL 230 Pylon-Condition #16	251	100%
54	C-10i	14 July 76	BL 144 Pylon-Condition #9	261	100%
55	C-10j	15 July 76	BL 144 Pylon-Condition #10	262	100%
56	C-10k	16 July 76	BL 144 Pylon-Condition #11	263	100%
57	C-10l	19 July 76	BL 144 Pylon-Condition #12	264	100%
58	C-20	22 July 76	Pave Penny Pylon Component Test	271	100%
59*	C-15i	27 July 76	Yaw Control-Rt Stop	281	100%
60*	C-15g	28 July 76	Yaw Control-Power Mode, Rt Pedal	282	100%
61*	C-21	4 Aug 76	Aileron Geared Tab Component Test	178	80%
62	C-3d	17 Aug 76	Deceleron Component Test #4	206	100%
63	C-15a	20 Aug 76	Roll Control-Power Off Mode, Roll Rt	291	100%
64	C-15a	20 Aug 76	Roll Control-Power Off Mode, Roll Lt	292	100%

ITEM NO	COND NO	TEST DATE	TEST CONDITION	DATA S/N	PERCENT DUL SUPPORT
65	C-15b	23 Aug 76	Roll Control-Lt Stop	293	100%
66	C-15b	23 Aug 76	Roll Control-Rt Stop	294	100%
67	C-13b	26 Aug 76	Canopy Gust Load-Condition II	**	100%
68	C-13a	31 Aug 76	Canopy Gust Load-Condition I	302	100%
69	C-15j	3 Sept 76	Brake System-Both Pedals	311	100%
70	C-15k	8 Sept 76	Brake System-Single Pedal	312	100%
71*	C-13c	21 Sept 76	Cockpit Pressurization	303	60%
72*	C-15h	30 Sept 76	Yaw Control-Manual Reversion	284	90%
73*	C-15h	4 Oct 76	Yaw Control-Manual Reversion	285	100%
74	C-17	13 Oct 76	Landing Gear Pod	321	100%
75*	C-13c	15 Oct 76	Cockpit Pressurization	305	72.5%
76	C-14a	2 Nov 76	Fwd Fuselage Hoisting Load	331	100%
77	C-14c	5 Nov 76	Fwd Fuselage Jack Loads + Fwd Load	332	100%
78	C-14b	8 Nov 76	Fwd Fuselage Jack Loads + Side Load	333	100%
79	C-14e	12 Nov 76	Aft Fuselage Jack Loads + Aft Load	334	100%
80	C-14d	16 Nov 76	Aft Fuselage Jack Loads + Side Load	335	100%
81	C-14g	22 Nov 76	Wing Jack Loads + Fwd Load	336	100%
82	C-14f	23 Nov 76	Wing Jack Loads + Side Load	337	100%
83		24 Nov 76	600 Gallon Tank Modified Lug	341	148%
84	A-6	10 Feb 77	RPM-BDW-750-05 (5.86g)	352	100%
85	C-18	22 Feb 77	Nacelle Doors Open	361	100%
86	C-22	12 Apr 77	Demonstration of the Non-Binding Operation of the Primary Flight Control System	374	
87*	A-1	19 May 77	PB-BDW/MFCG-750-05 (7.33g)	383	127%
88*	A-6	12 Aug 77	RPM-BDW-750-05 (5.86g)	392	133%
89*	A-6	29 Aug 77	RPM-BDW-750-05 (5.86g)-Revised	393	158%
90*	C-6c	8 Sept 77	NLG Unsymmetrical Brake Left	146	150%
91*	C-8a	18 Oct 77	MLG Two Point Braked Roll	157	113%
92*	C-22	1 Mar 78	ACES II HTES Seat Support Structure	402	93%

*These items are explained on following pages.

**Data not recorded through the data system.

ITEMS 1 & 87

There was a failure in the test hardware at approximately 95% DUL. This condition was repeated as a failing load test (Item 87). The structure supported 127% DUL. At this load, the upper inboard cover of the wing failed between BLO and LBL23. Damage to the structure after the failing load test is shown in Figures 8 through 18.

ITEM 34

The Yaw Right Condition (Cond. C-15g) was started with the pedals in the neutral position at no load. At approximately 30% DUL, the right pedal was against the stop. While loading from 67% DUL to 75% DUL, a pushrod (P/N 160C123005) buckled (Fig. 19). It was found that the pushrod had not been adjusted to the correct length when it was installed.

ITEM 35

The Yaw Left Condition (Cond. C-15f) was then run with the left pushrod adjusted to the correct length and with the left pedal in the most aft position at no load. The system supported 100% DUL.

ITEM 36

The Yaw Right Condition was repeated using the 005 pushrod from the left side of the system in place of the one that failed. The test was started with the right pedal in the most aft position with no load. The system supported 100% DUL. However, while returning to zero load, the 005 pushrod buckled at approximately 30% DUL. It appeared that the self-aligning rod ends became jammed. This then introduced a bending moment into the pushrod and caused it to fail.

ITEM 37

The four Deceleron Component Tests (C-3a thru C-3d) had three different speed brake settings; 0%, 50% and 80%. The speed brake settings were to be maintained by the speed brake actuator. During the test system check run for Test #1 (Cond C-3a) it was not possible to maintain the speed brake setting with the actuator. It was decided to replace the actuator with a solid link for each of the deceleron tests. Three separate links were designed and fabricated to maintain the speed brakes in the three different settings.

ITEM 38

Before running the Right Stop Test (Cond. C-15i), the 005 pushrods were replaced with instrumented, fixed length pushrods (P/N 160C123003). The right 003 pushrod failed at 80% DUL during this test. An inspection of the yaw control system showed that the right stop was not the proper length. An inspection of all in service aircraft with this type of stop showed that this problem existed in several of these airplanes. The problem was corrected by FRC TCD 0244.

ITEMS 42 & 47

At 97% DUL, the aft hook of the MAU-40 rack failed. The rack was government furnished equipment. The investigation of the failure showed that although the rack had seen prior service, the hooks were understrength. A new rack was installed in the pylon and the test repeated. The new rack and pylon supported 100% DUL.

ITEM 59

The Right Stop Test discussed in Item 38 was repeated with the modified stop and the system supported 100% DUL.

ITEM 60

This test was a repeat of the test discussed in Item 36. While loading to 100% DUL, the right hand 003 pushrod failed. There was apparent yielding at 85% DUL.

ITEM 61

At 80% DUL, the Trim Tab Drive Pushrod (P/N 160C622007) buckled (Fig. 20). The critical design condition for which the geared tab was tested was the powered mode at 450 KEAS with the aileron 21° TED and a 0% speed brake setting, tab at 45° and tab hinge moment of - 6940 inch-pounds ultimate. However, based on flight test data, the maximum tab hinge moment is - 3720 inch-pounds. This occurs in the powered mode at 450 KEAS with the aileron at 28° TEU and a 40% speed brake setting. Based on the above facts, FRC concluded that the aileron tab components did pass the required static ultimate test and no further testing would be required. The A-10 SPO concurred with this opinion.

ITEMS 71 & 75

While approaching limit pressure (4.9 psig) for the Cockpit Pressurization Test, a noise was heard and the cockpit pressure dropped. It was found that the right hand canopy support fittings had become disengaged due to the aft movement of the canopy as the pressure was increased. The fittings attached to the cockpit side rails (P/N 160D116049) are aluminum, the fittings on the canopy (P/N 160D117244) are steel. The failure occurred when the canopy had moved aft to a point where the canopy fitting sheared off a portion of the side rail fitting (Fig. 21). It was also found that the right hand side rail fitting had been installed 3/16" aft of center. The left hand fitting was 1/8" aft of center. The side rail fitting was re-designed by FRC with a wider flange (.625 inch). The re-designed parts were installed and the test re-run. At a cockpit pressure of 5.35 psig (72.9% DUL) the same type of failure occurred (Fig. 22). There were secondary failures of the canopy and of the right hand cockpit side rails (Fig 23 thru 26).

Because of the cost to repair the static test article it was decided to repeat the test on the fatigue test article at FRC. The test was conducted by FRC personnel. The test was run with a stop incorporated into the canopy actuation system which limited the aft motion of the canopy during pressurization of the cockpit. This test method was approved by the A-10 SPO. FBT was not consulted about using the stop. The rationale for using this method and the test results are discussed in FRC Report GT 160SR059, "A-10 Full Scale Static Test Report, Cockpit Pressurization Test".

ITEMS 72 & 73

The Yaw Control Subsystem, Manual Reversion Mode Test (C-15h) was started with the bellcrank 1/4" from the stop. The bellcrank was against the stop at approixmately 63% DUL. The test was re-started with the bellcrank 1/2" from the stop. While loading from 90% to 95% DUL, the load started to drop. The test was stopped to review the data and inspect the system, no damage was found. The test was re-started. At 60% DUL, the observer in the cockpit reported that the bellcrank appeared to be rolling. The system was inspected and there being no apparent damage, testing was continued. While loading to 90% DUL the applied load started to drop. The test was stopped and inspection of the system showed that the Rudder Pedal Output Yaw Crank (P/N 160D123150) was bent (Fig. 27 and 28). The crank from the left side of the system was removed and installed in place of the damaged crank. The test was repeated and the system supported 100% DUL.

ITEMS 88 & 89

The Empennage Failing Load Test (Condition RPM-BDW-750-05 / 5.86g) was run to demonstrate the growth potential of the empennage. During the first run (Item 88), there was a failure in the left engine vertical load fitting at 133% DUL. In an attempt to induce a failure in the vertical tail, FRC revised the empennage loads for the second run (Item 89). However, the Right Hand Horizontal Tail failed at 158% DUL. This figure is based on the original empennage loading condition. Damage to the structure is shown in Figures 29 through 31.

ITEM 90

The Nose Landing Gear Support Structure Failing Load Test (Unsymmetrical Brake Left Condition) was run to 150% DUL. The test was stopped at this point since there were no apparent structural failures.

ITEM 91

The Main Landing Gear Support Structure Failing Load Test (Two Point Brake Roll Condition) was run to 113% DUL. At this load, the drag strut pickup lugs on the socket pin failed (P/N 19062). The failure and damaged parts are shown in Figures 32 through 36.

ITEM 92

The ACES II HTES Seat Support Structure Test was run to 93% DUL. At this load, the seat rails (P/N 160D188065-1 & -2) and the rail attachment lugs on the seat support casting (P/N 160D116027) failed. The A-10 SPO has determined that this load level is adequate for acceptance of the seat support structure. Therefore, a re-design and re-test of the structure is not necessary. The failure and damaged parts are shown in Figures 37 through 39.

IX. CONCLUSIONS AND RECOMMENDATIONS

Based on the results and observations obtained from the A-10 static test program, the following conclusions and recommendations are presented:

1. The primary structure satisfactorily supported the required design ultimate loads for all critical test conditions.

2. With the incorporation of the re-designed canopy fitting, the A-10 canopy is capable of supporting design ultimate load.

3. The results of the destruction tests indicate that the A-10 structure has more inherent strength than was assumed in the original design stress analysis. The results of the failing load tests are as follows:

   a. Wing failing load was 127% DUL.

   b. Horizontal tail failing load was 158% DUL. The vertical tail supported 137% DUL without failing.

   c. The nose landing gear support structure supported 150% DUL without failing.

   d. The main landing gear support structure supported 113% DUL without failing. However, strain gage data indicated imminent failure.

4. Because of the many problems experienced with the yaw control system, it is recommended that a production yaw control system be proof loaded. It is also recommended that the 160C123004 pushrod be re-designed to also allow for a compression loading caused by pulling back on a rudder pedal.

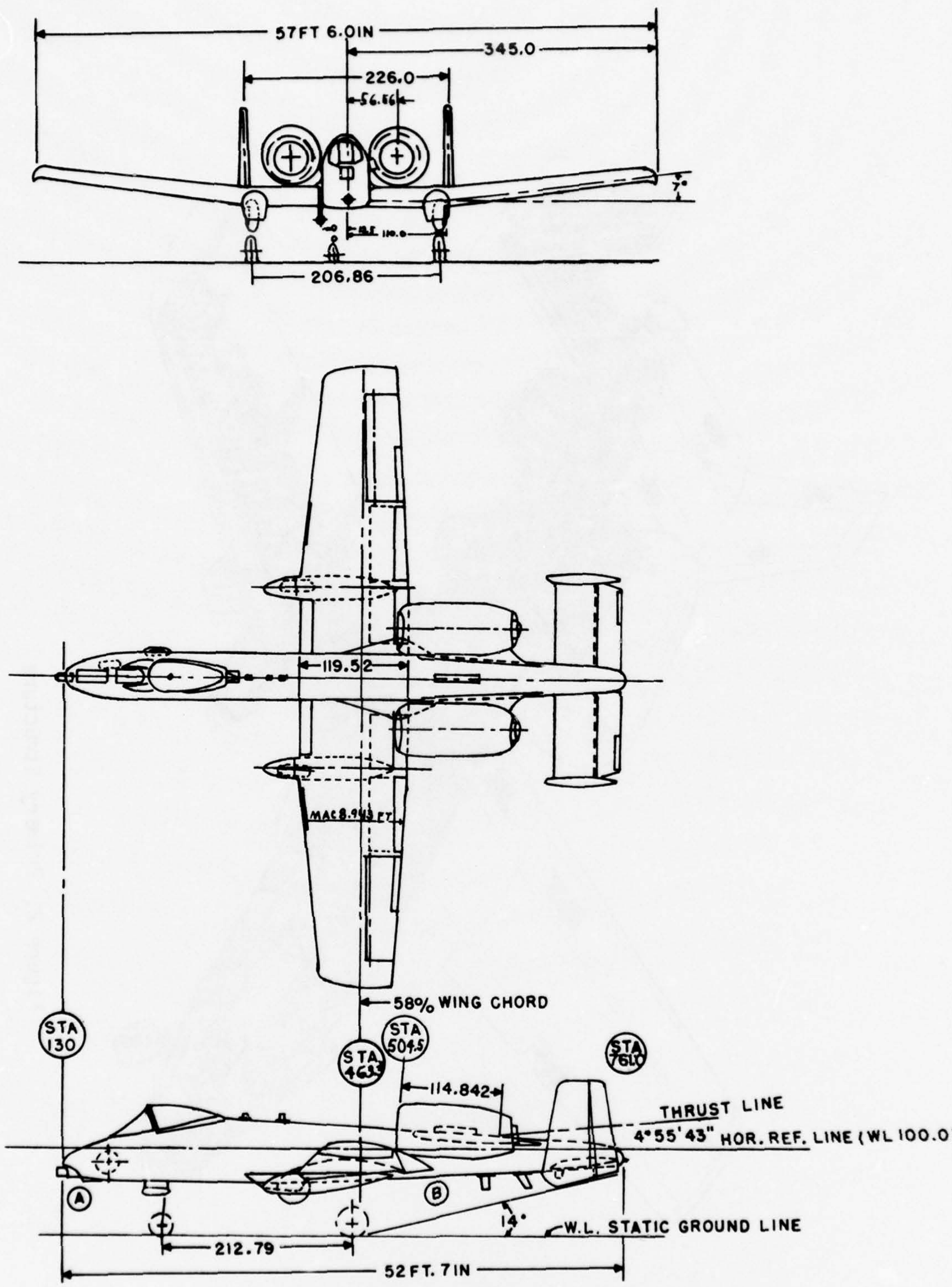

Figure 1. Three-View of Test Article

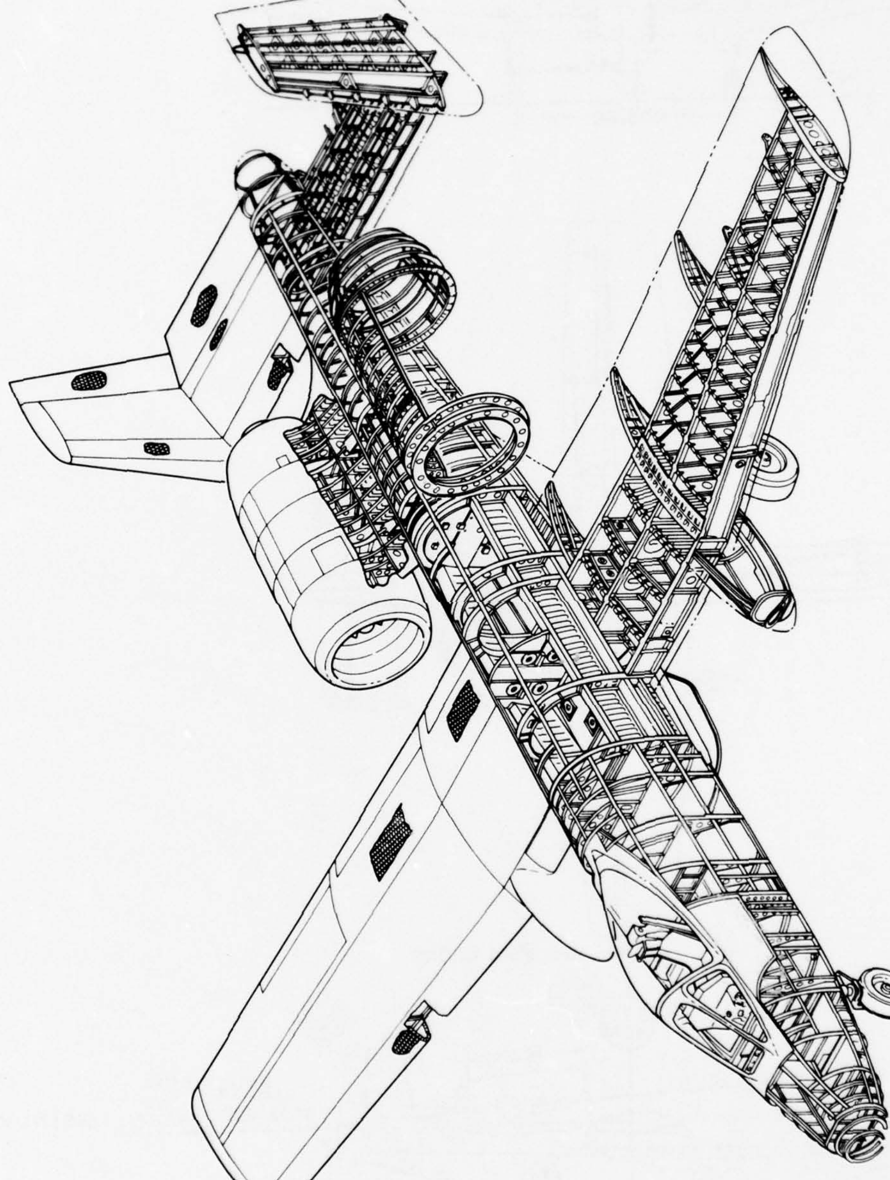

Figure 2. Primary Structure

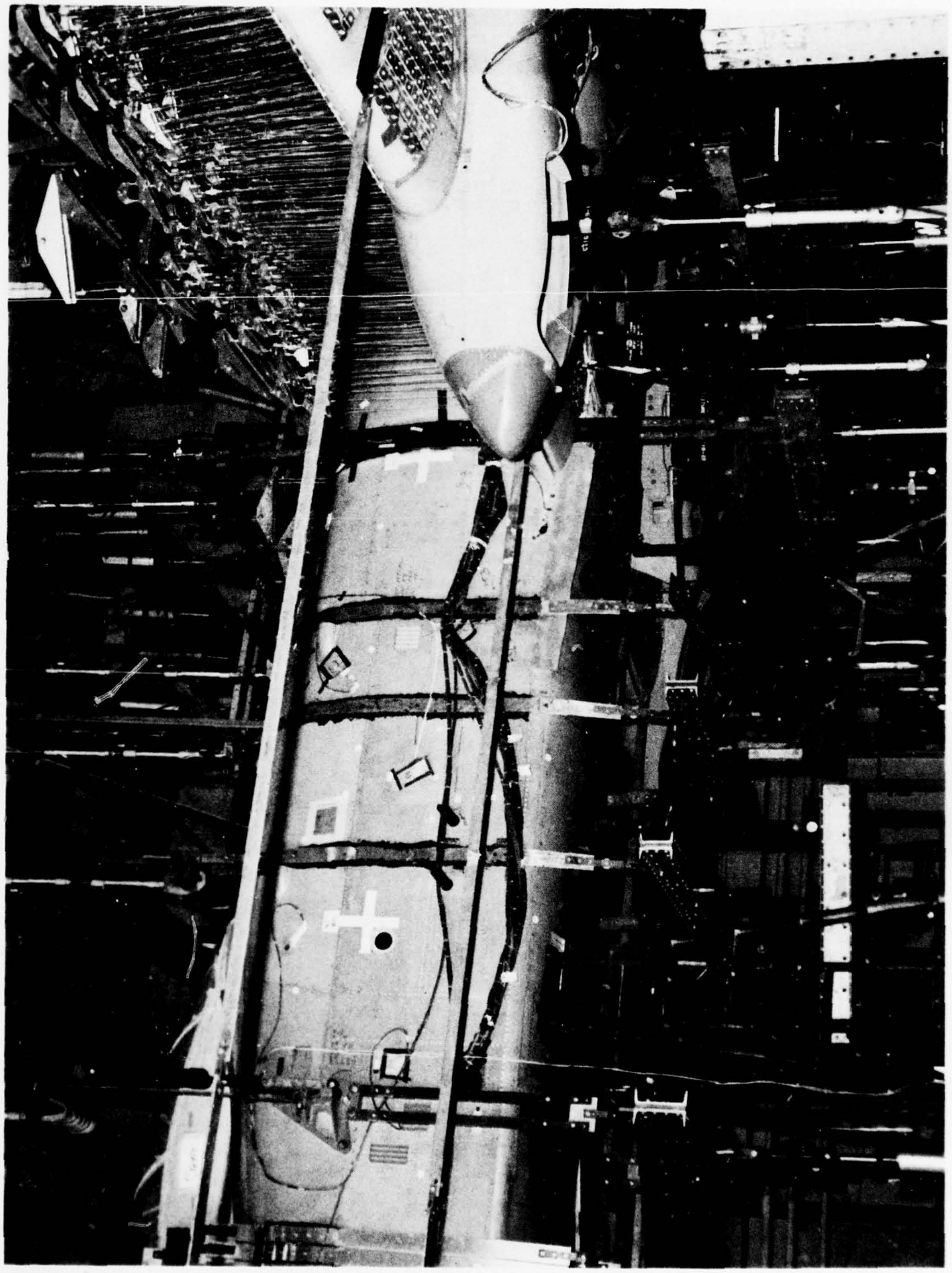

Figure 3. Typical Test Set-up - Wing and Fuselage

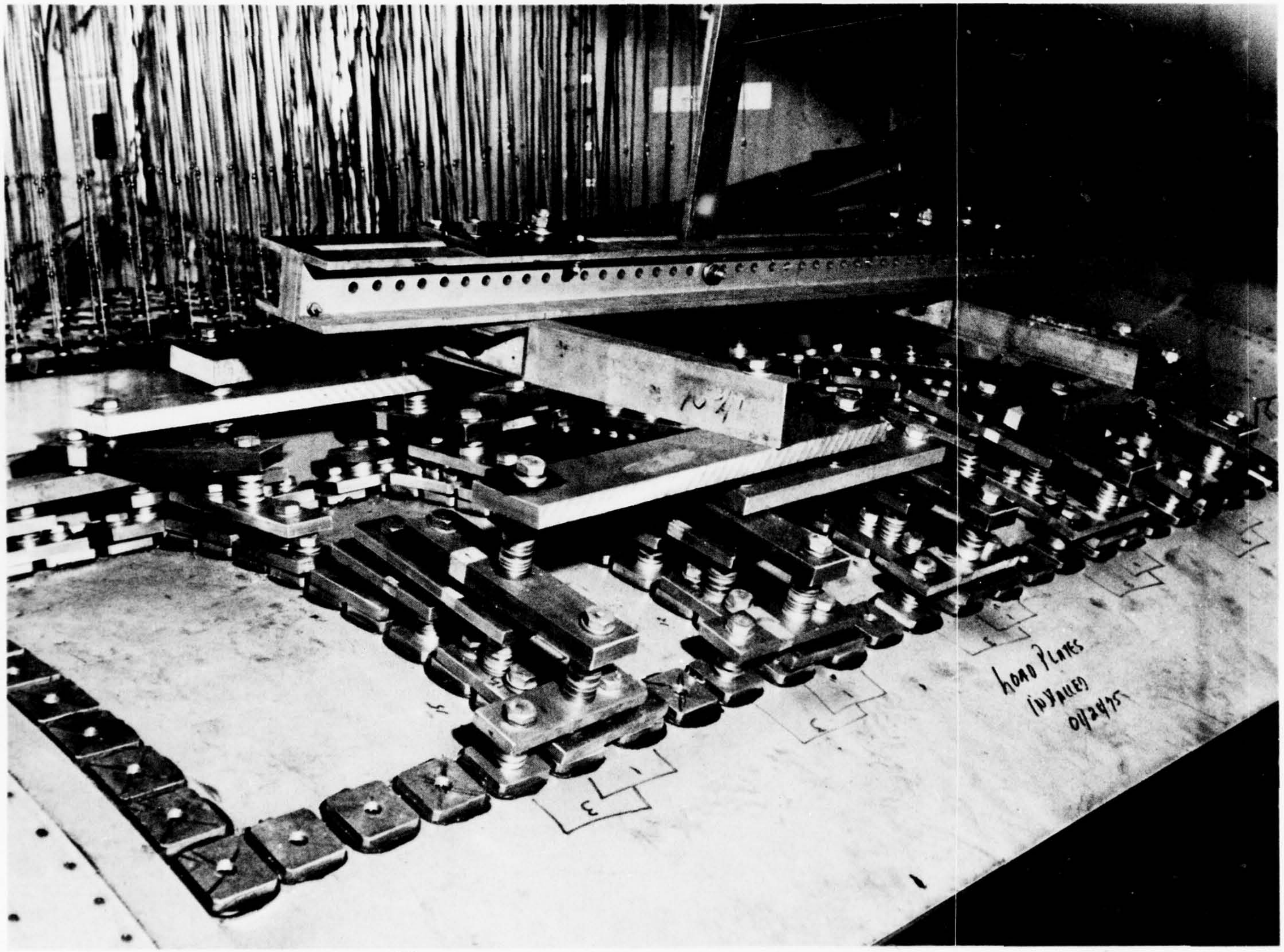

Figure 4. Typical Test Set-up - Flaps

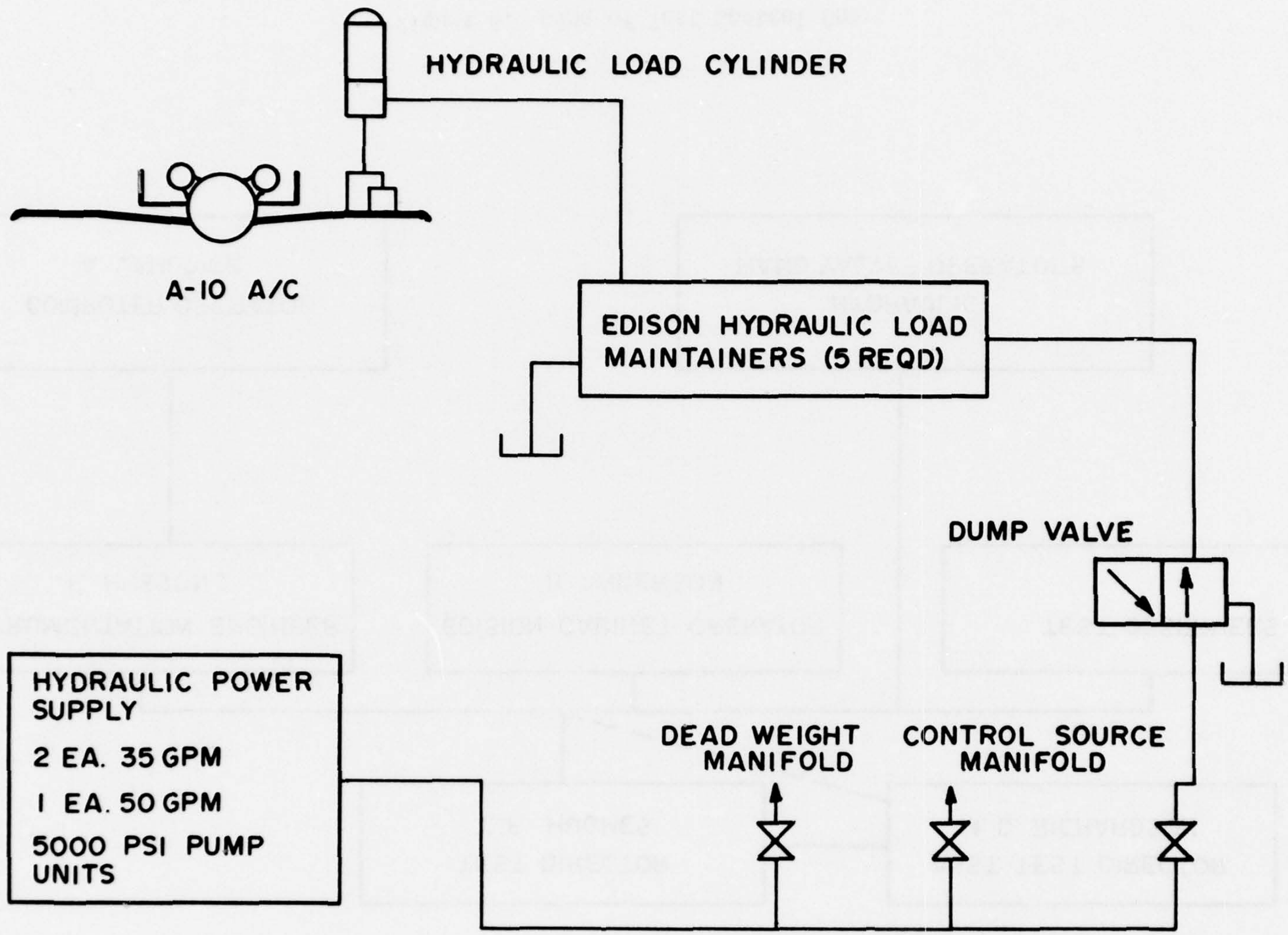

Figure 5. Hydraulic System Schematic

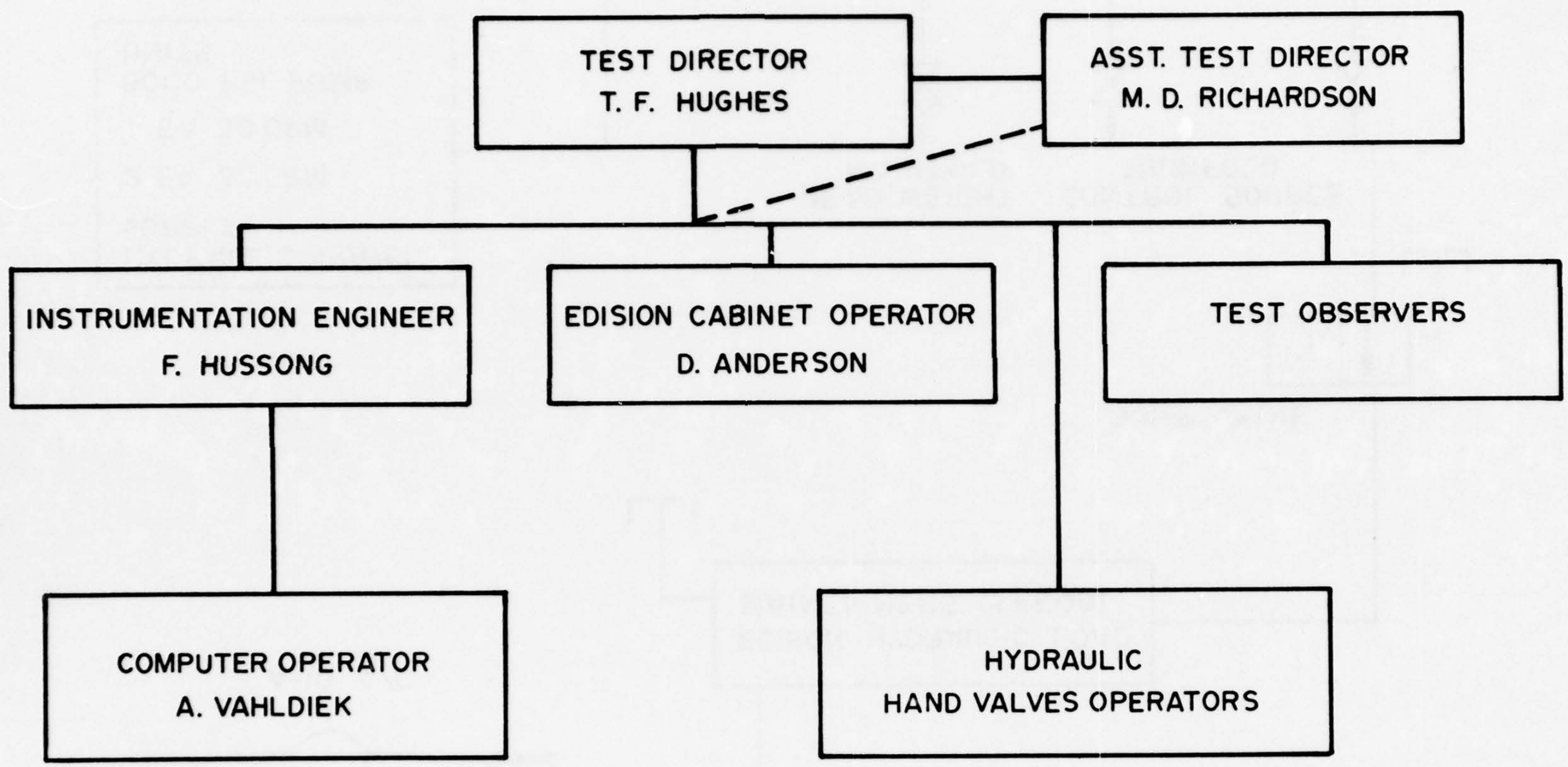

Figure 6. Line of Test Control Chart

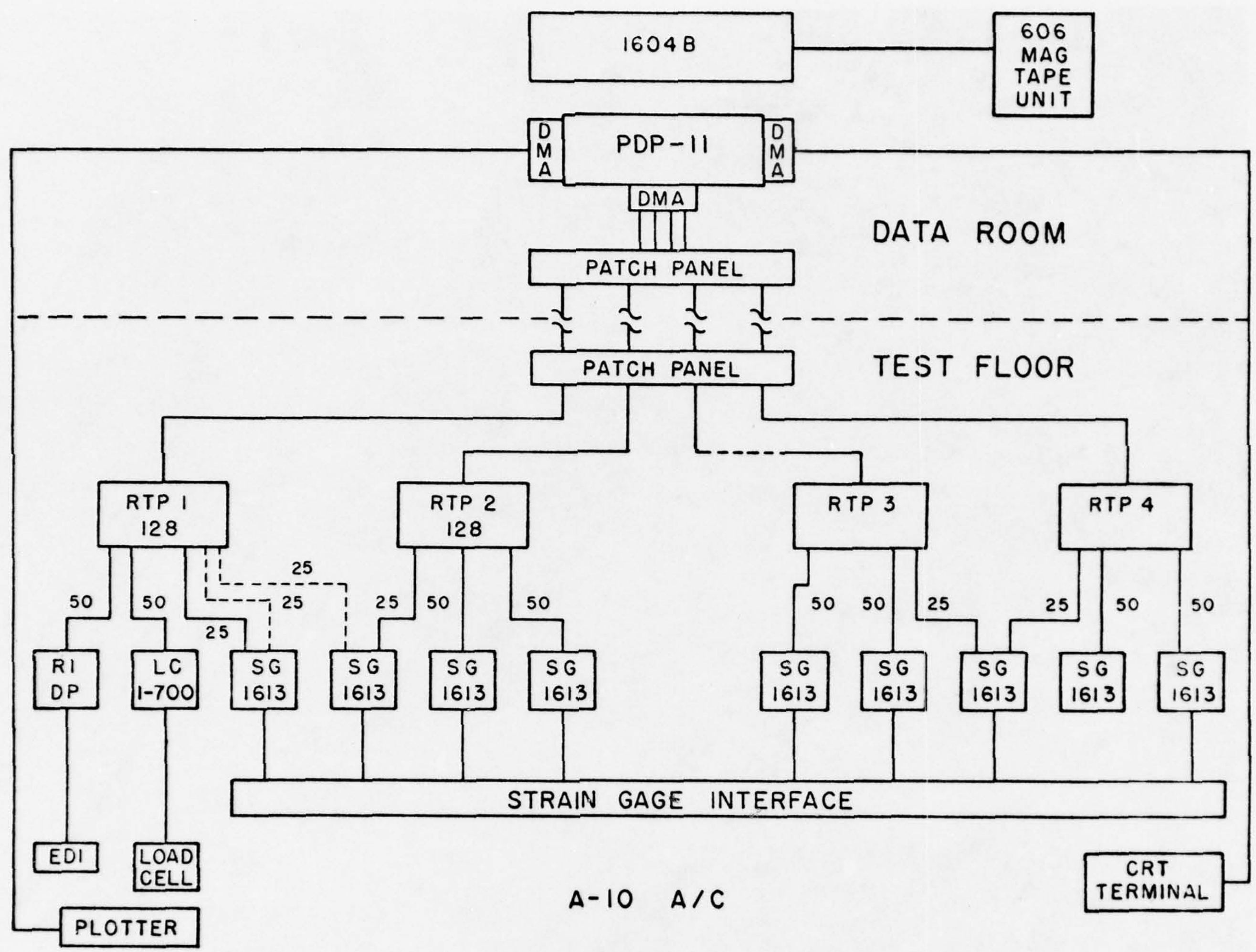

Figure 7. Data System Schematic

Figure 8. Damage After Failing Load Test - Left Side, Leading Edge, Inboard End

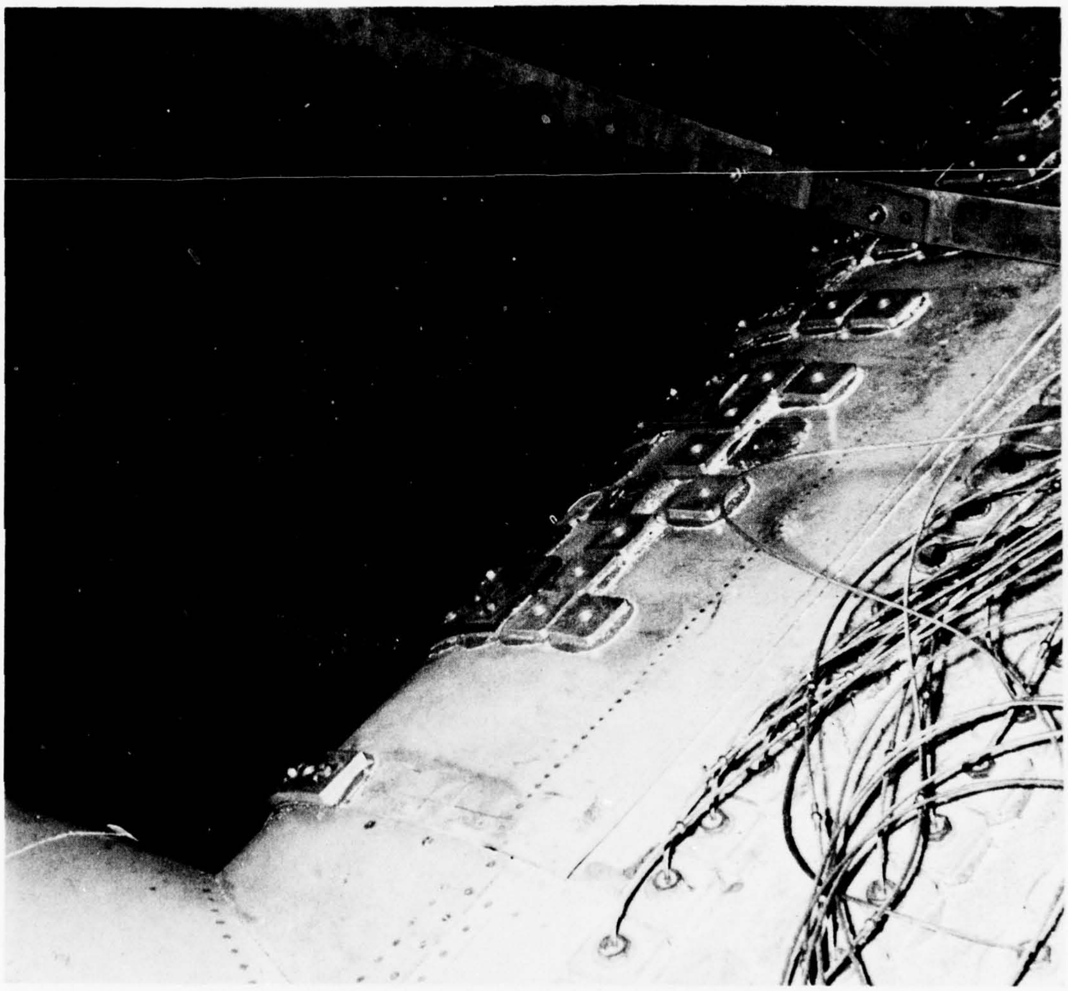

Figure 9: Damage After Failing Load Test-
Left Side Leading Edge Slat;
Outboard End

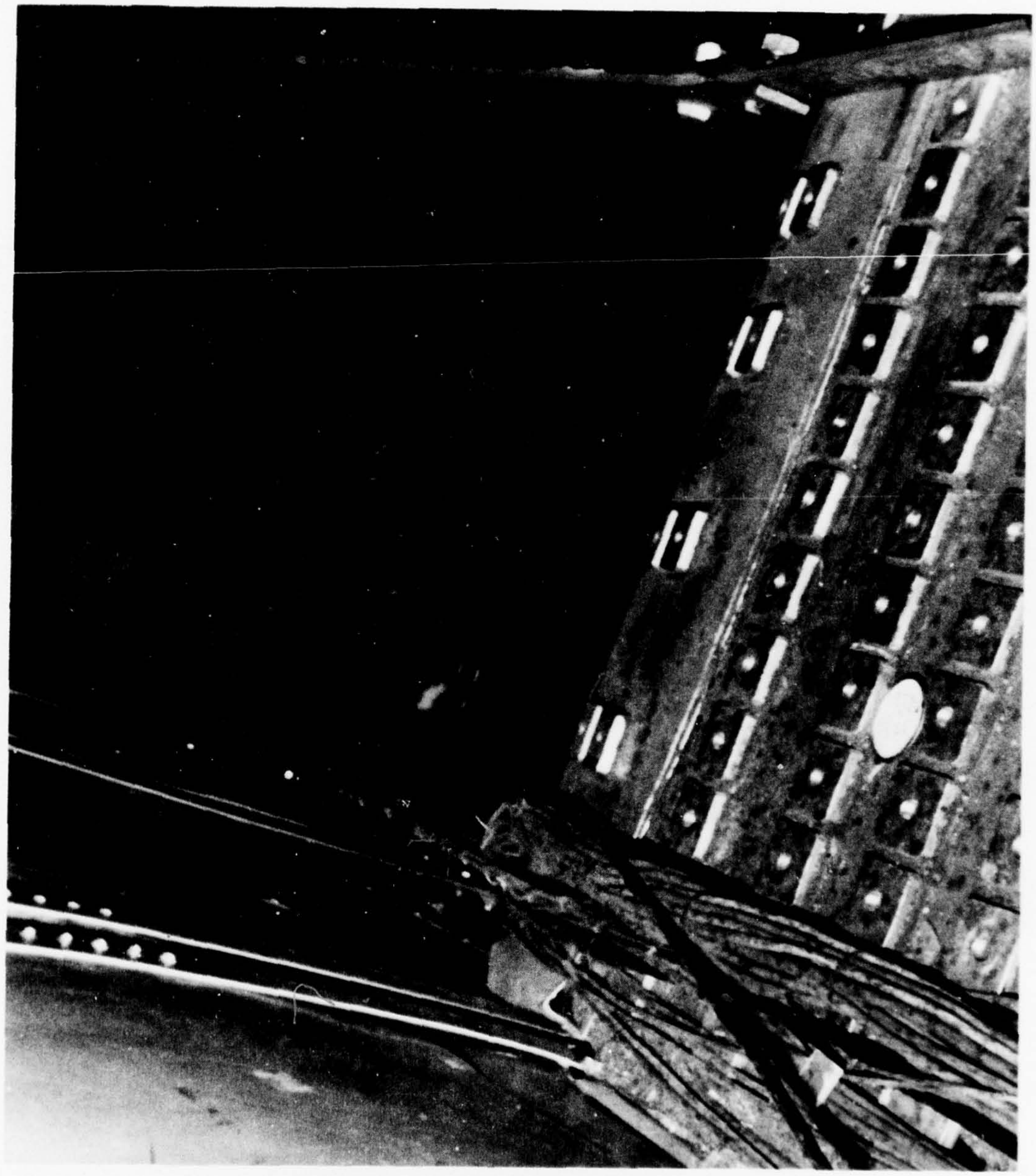

Figure 10: Damage After Failing Load Test-
Right Side Leading Edge Slat;
Inboard End

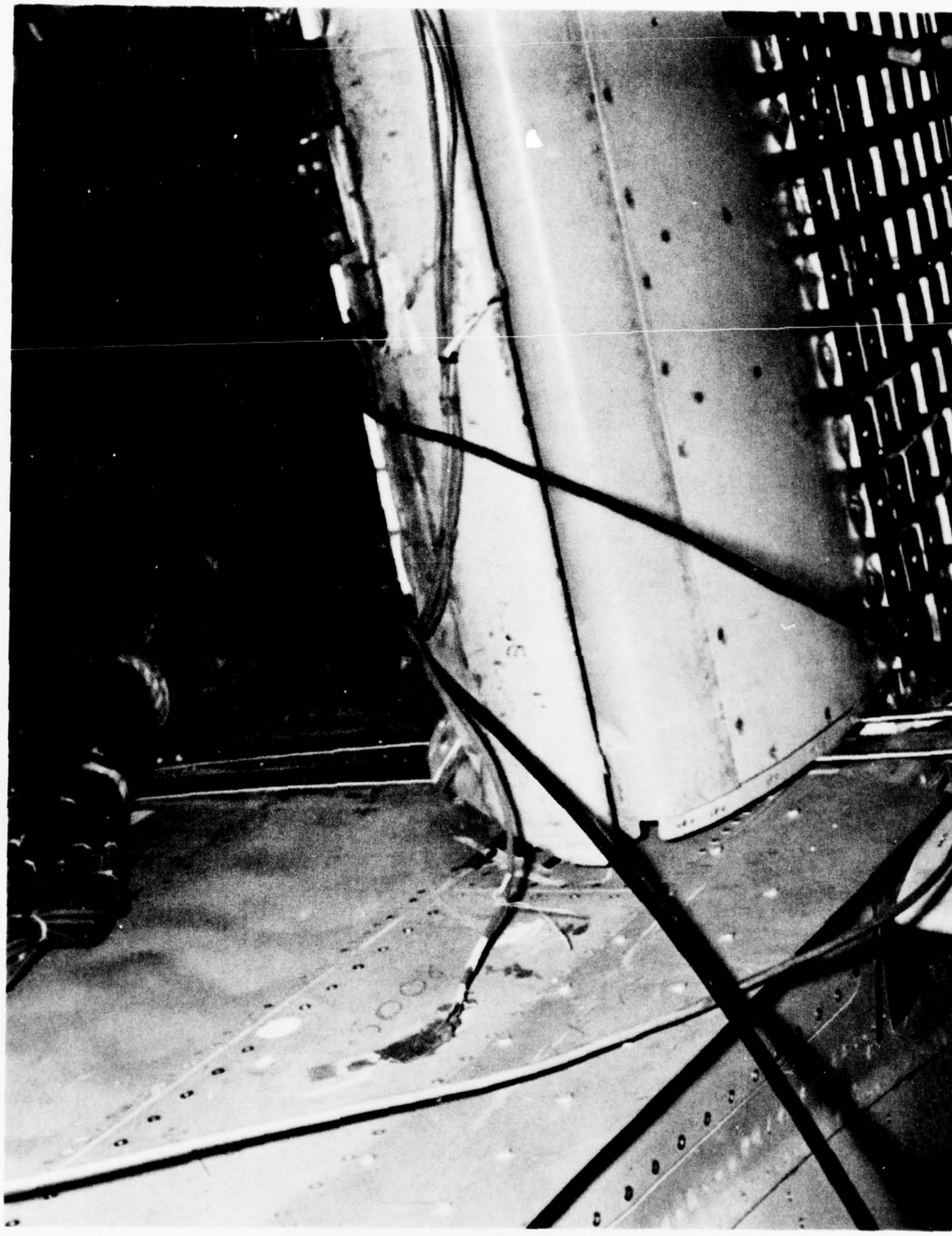

Figure 11: Damage After Failing Load Test-
Left Side Leading Edge Slat;
Inboard End

Figure 12: Damage After Failing Load Test-
Wing-Fuselage Fairing; Left Side

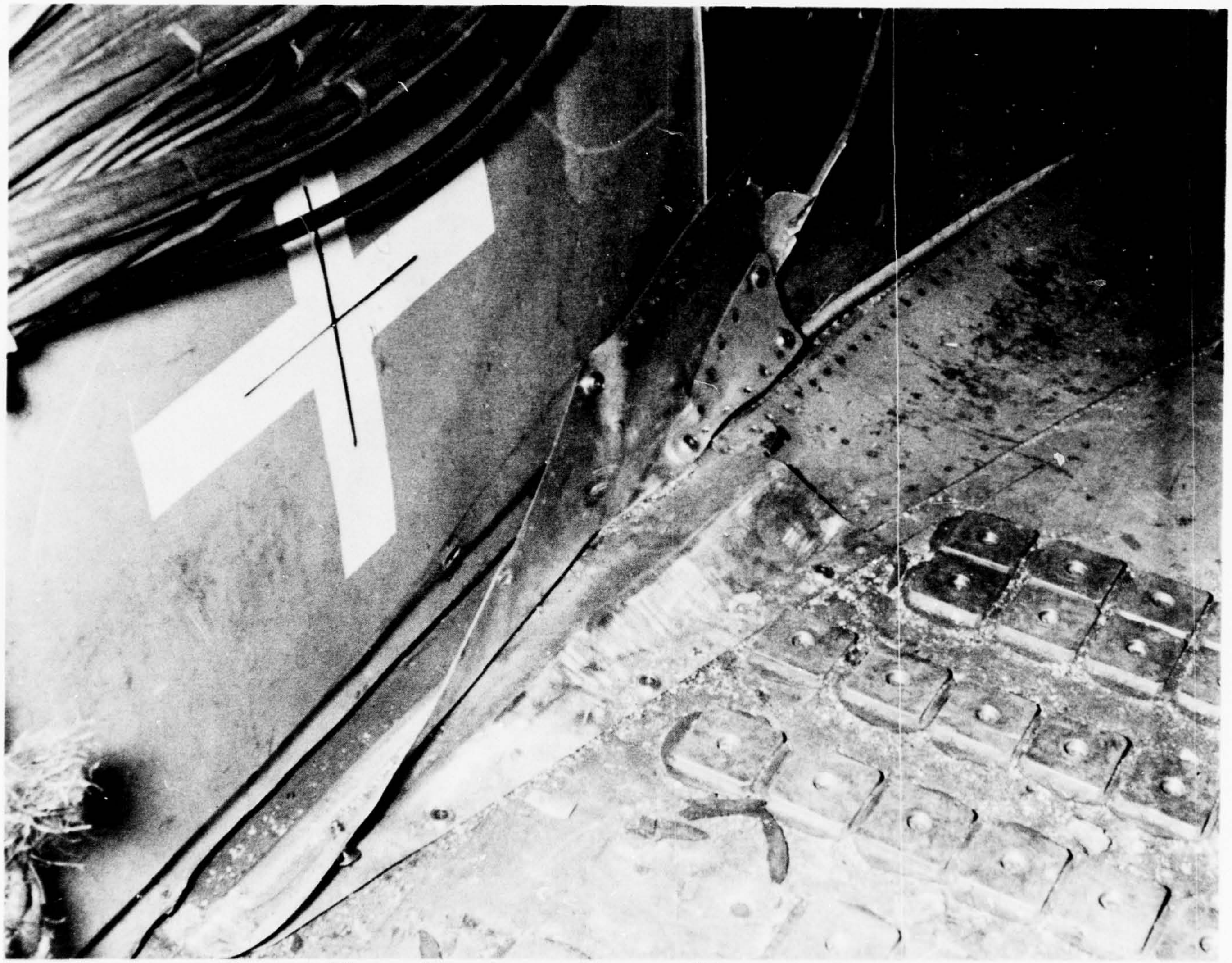

Figure 13: Damage After Failing Load Test-
Wing-Fuselage Fairing; Left Side

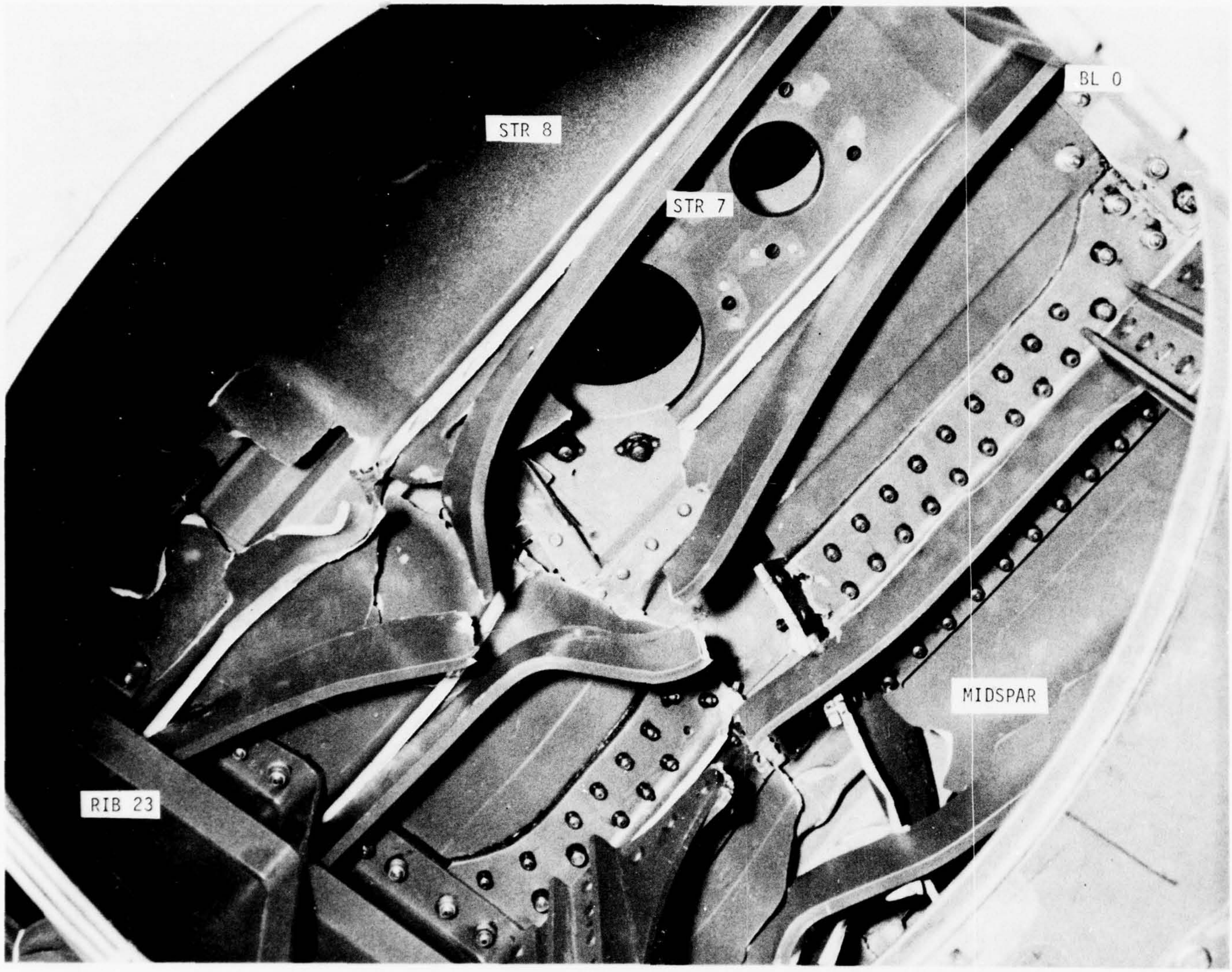

Figure 14. Inside of Wing Upper Cover Between BL 0 and LBL 23

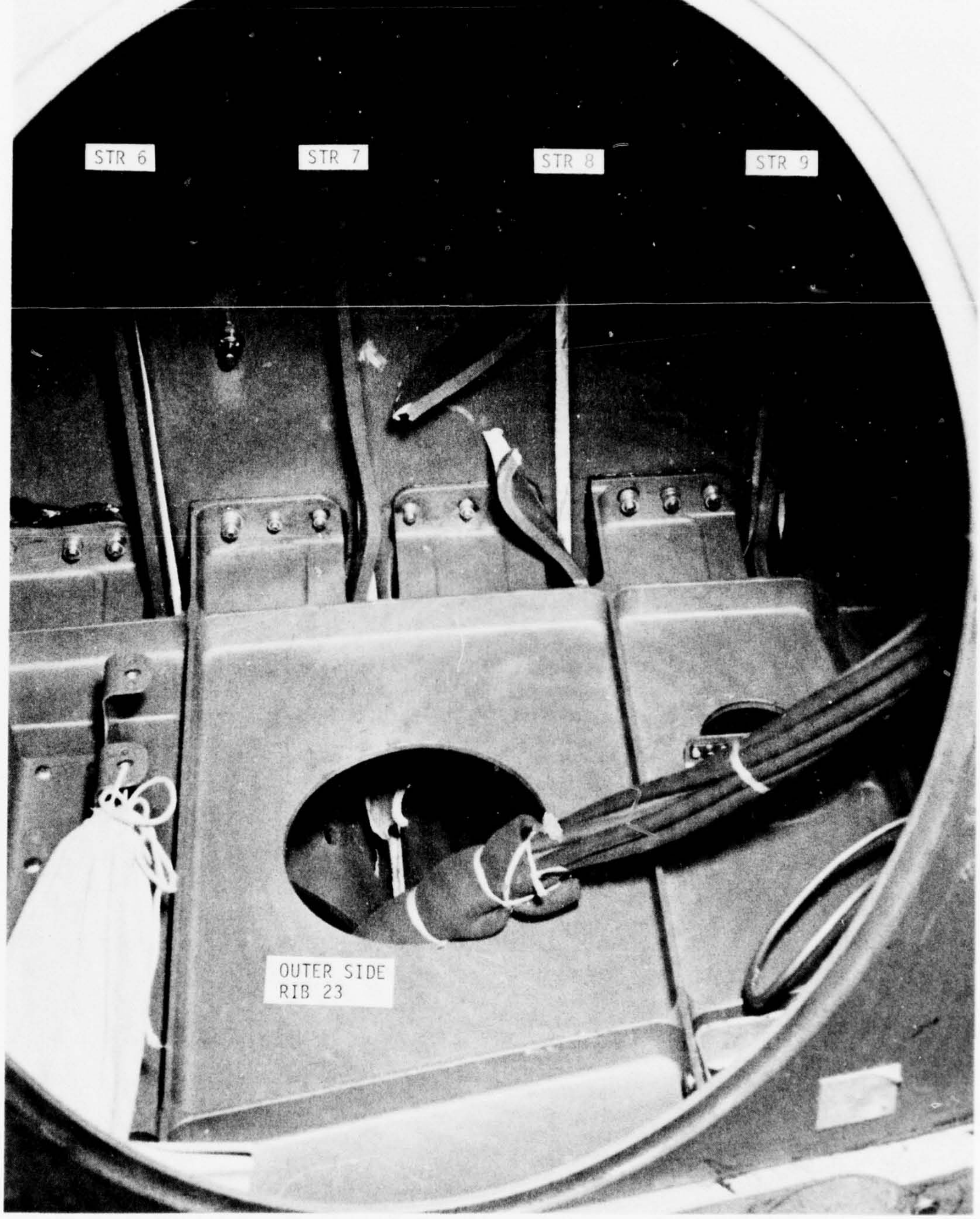

Figure 15. Inside of Wing Upper Cover Between LBL 23 and LBL 34

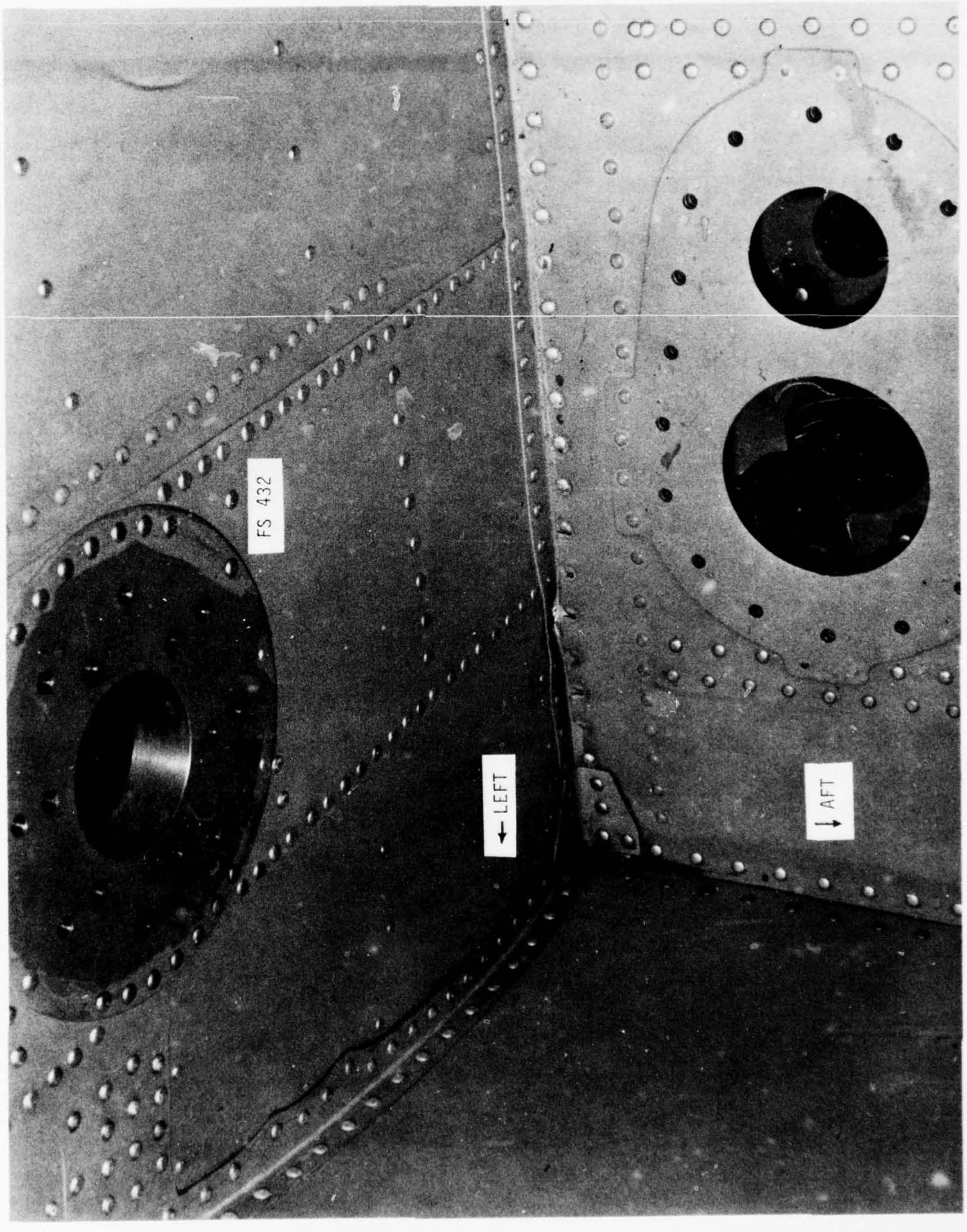

Figure 16. Inside of Fuselage Fuel Cell

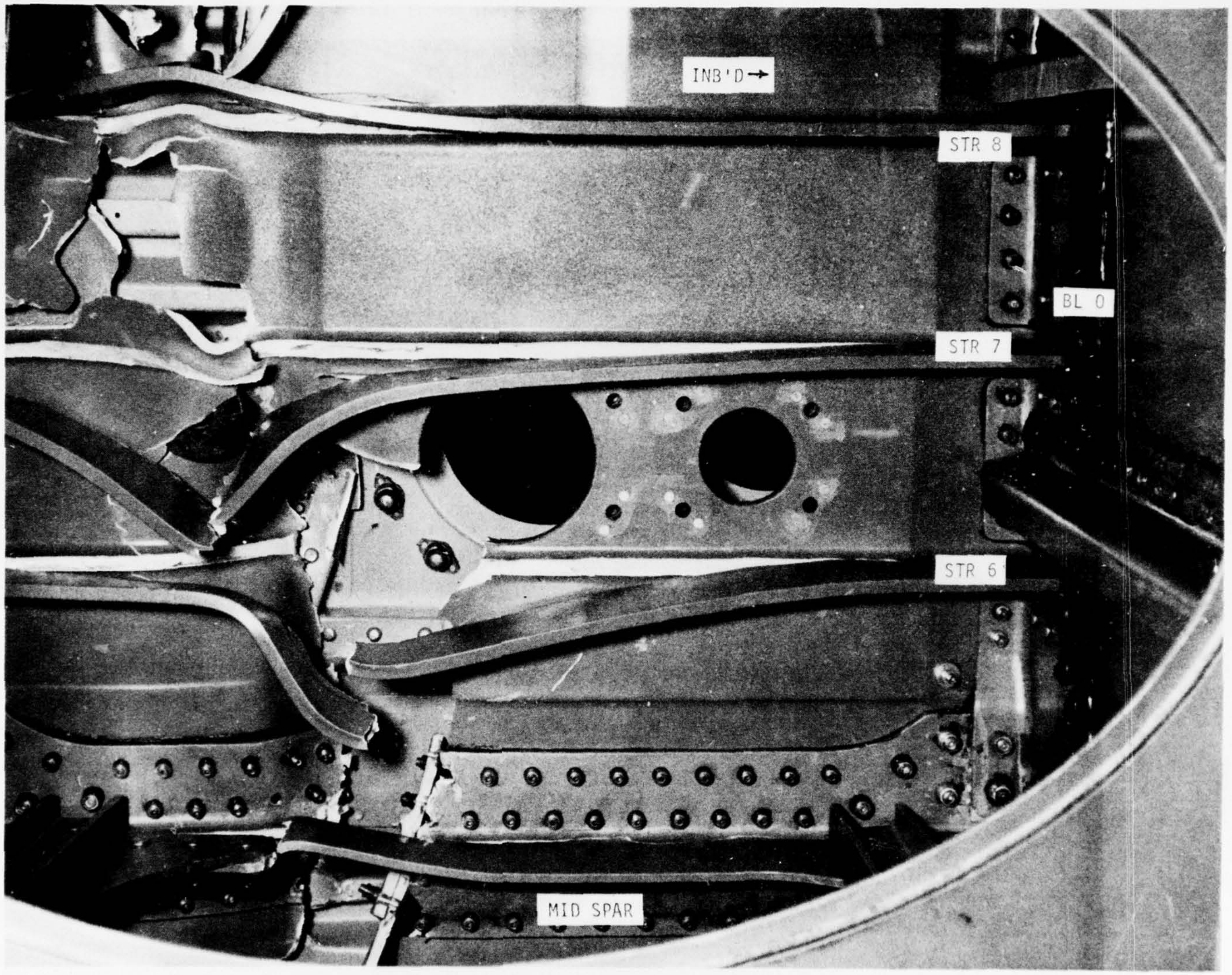

Figure 17. Inside of Wing Upper Cover Between BL 0 and LBL 23

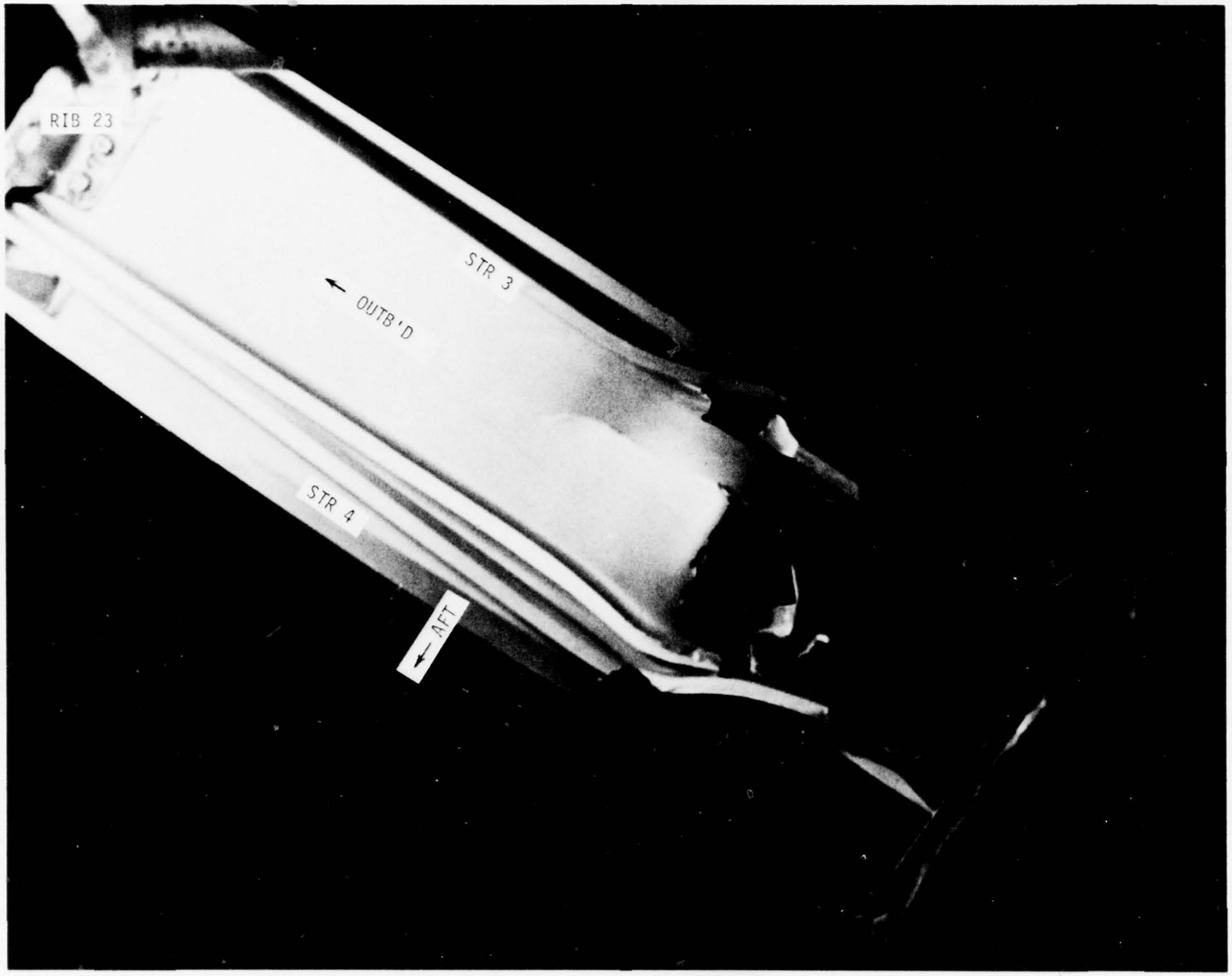

Figure 18. Inside of Wing Upper Cover Between BL 0 and LBL 23

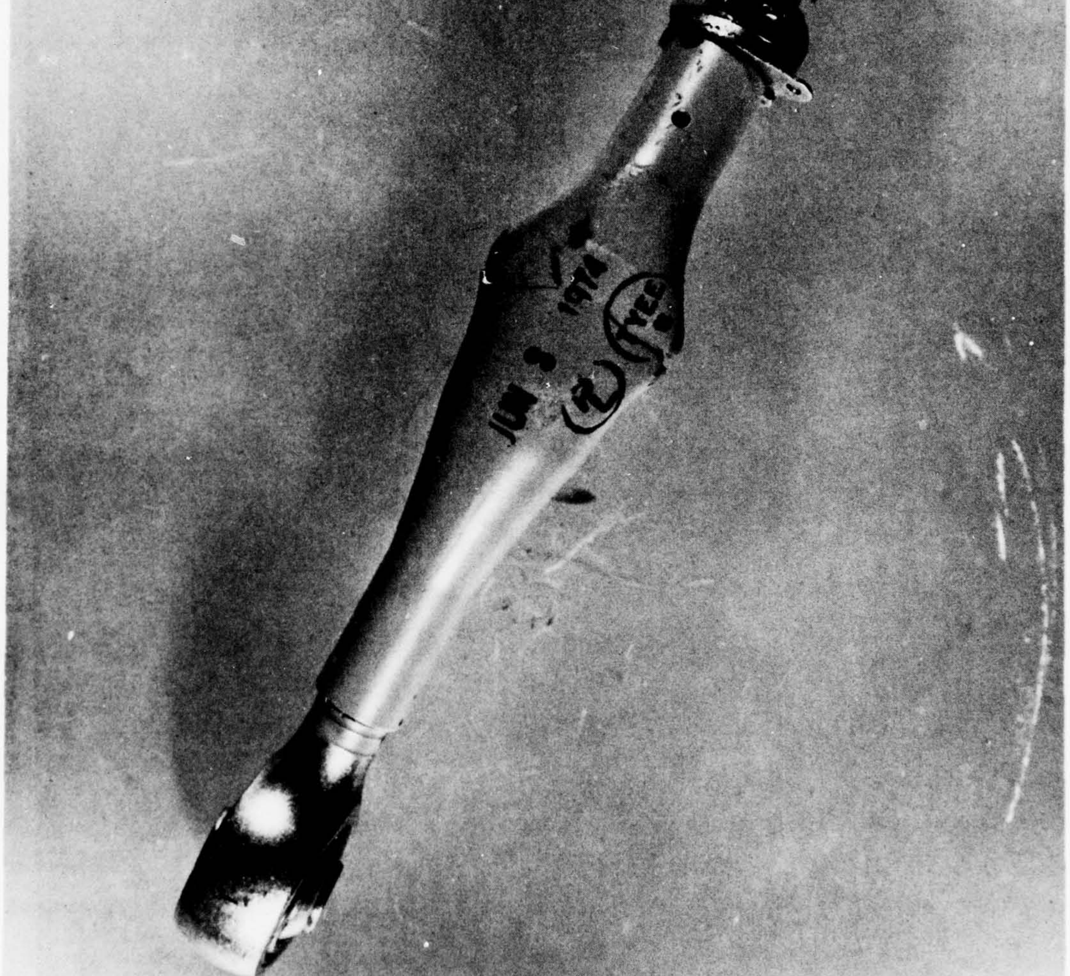

Figure 19. Failed Yaw Output Pushrod - Part No. 160C123005

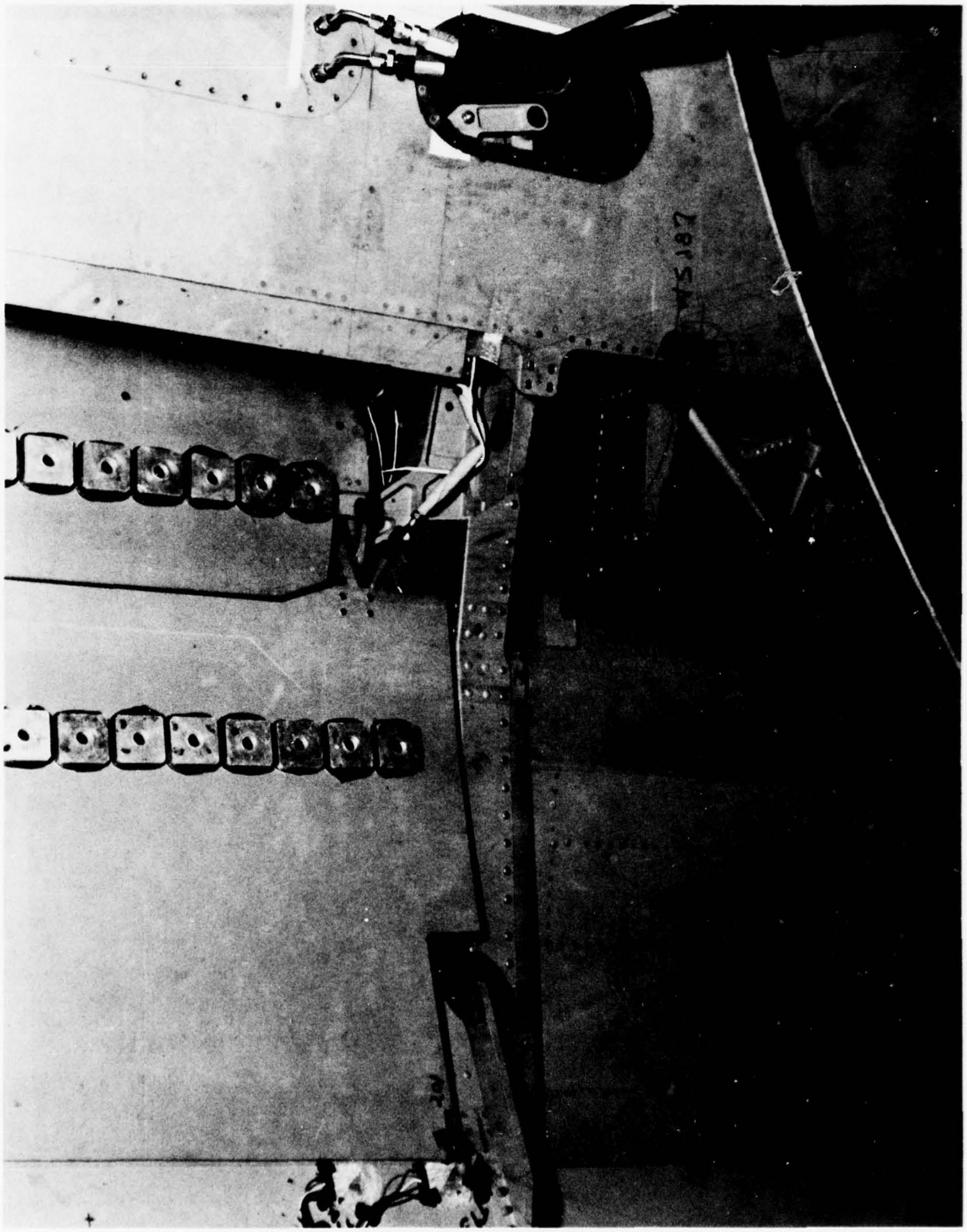

Figure 20. Failed Trim Tab Drive Pushrod - Part No. 160C622007

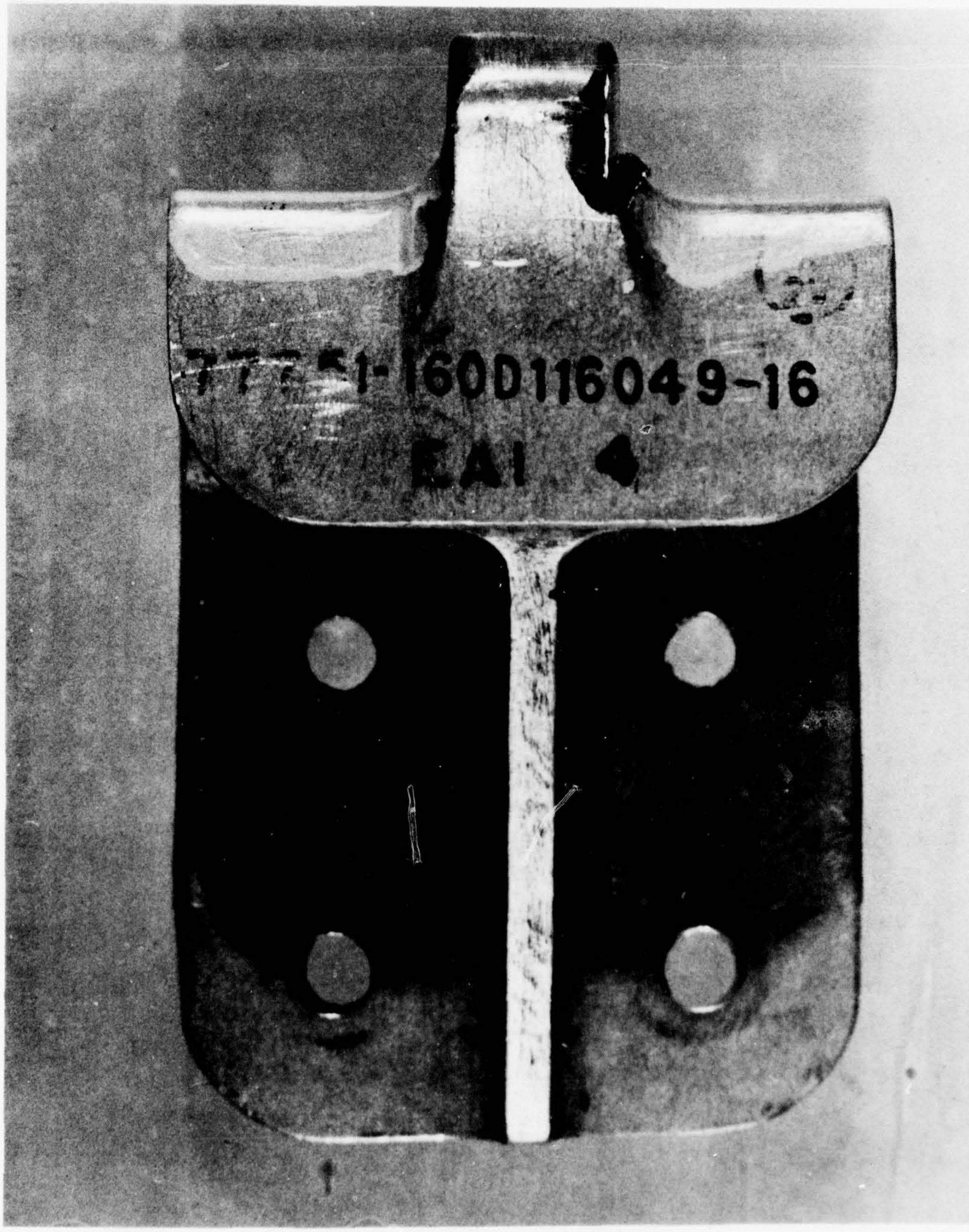

Figure 21. Failed Canopy Support Fitting - Part No. 160D116049-16

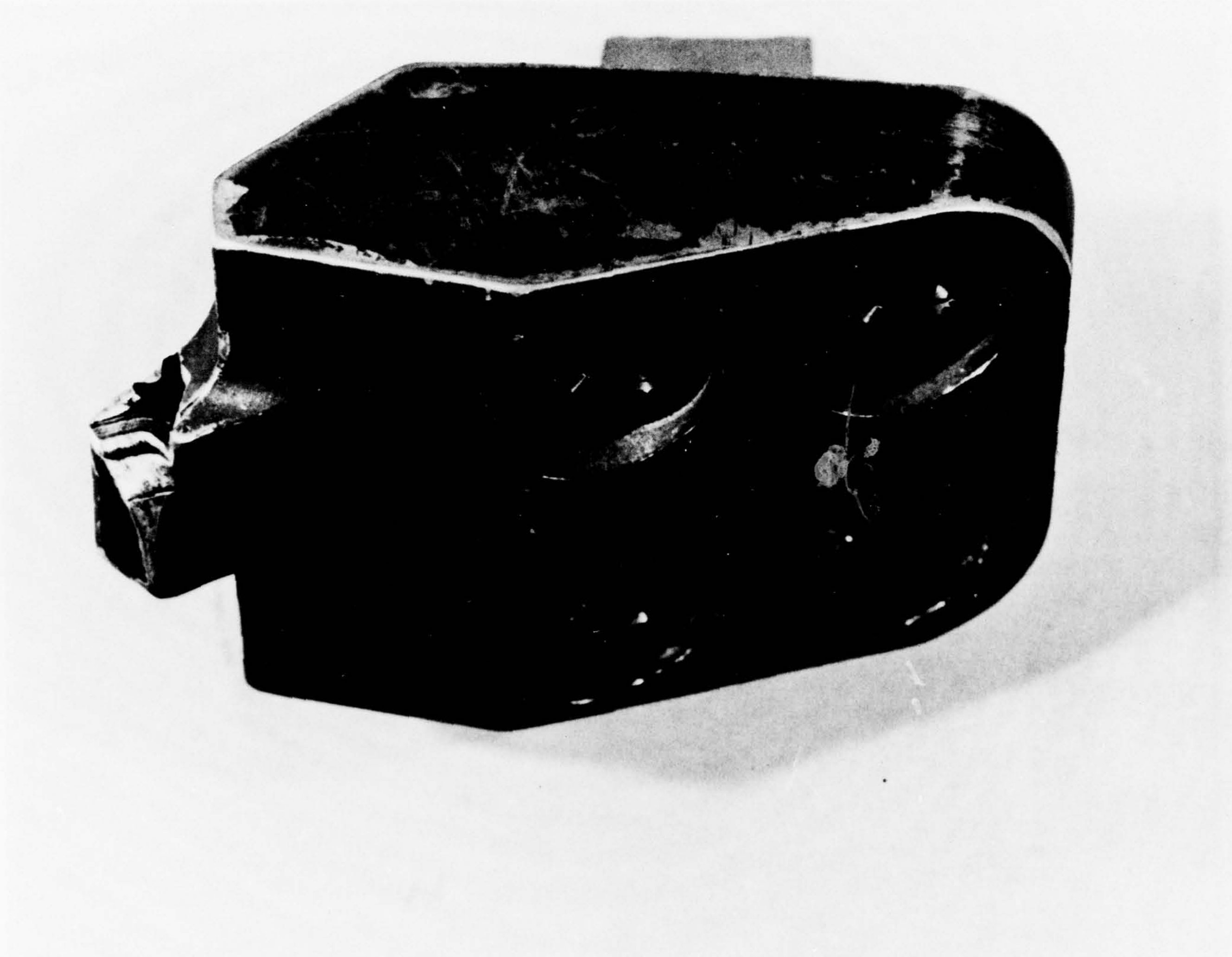

Figure 22. Failed Canopy Support Fitting - Part No. 160D116049-12

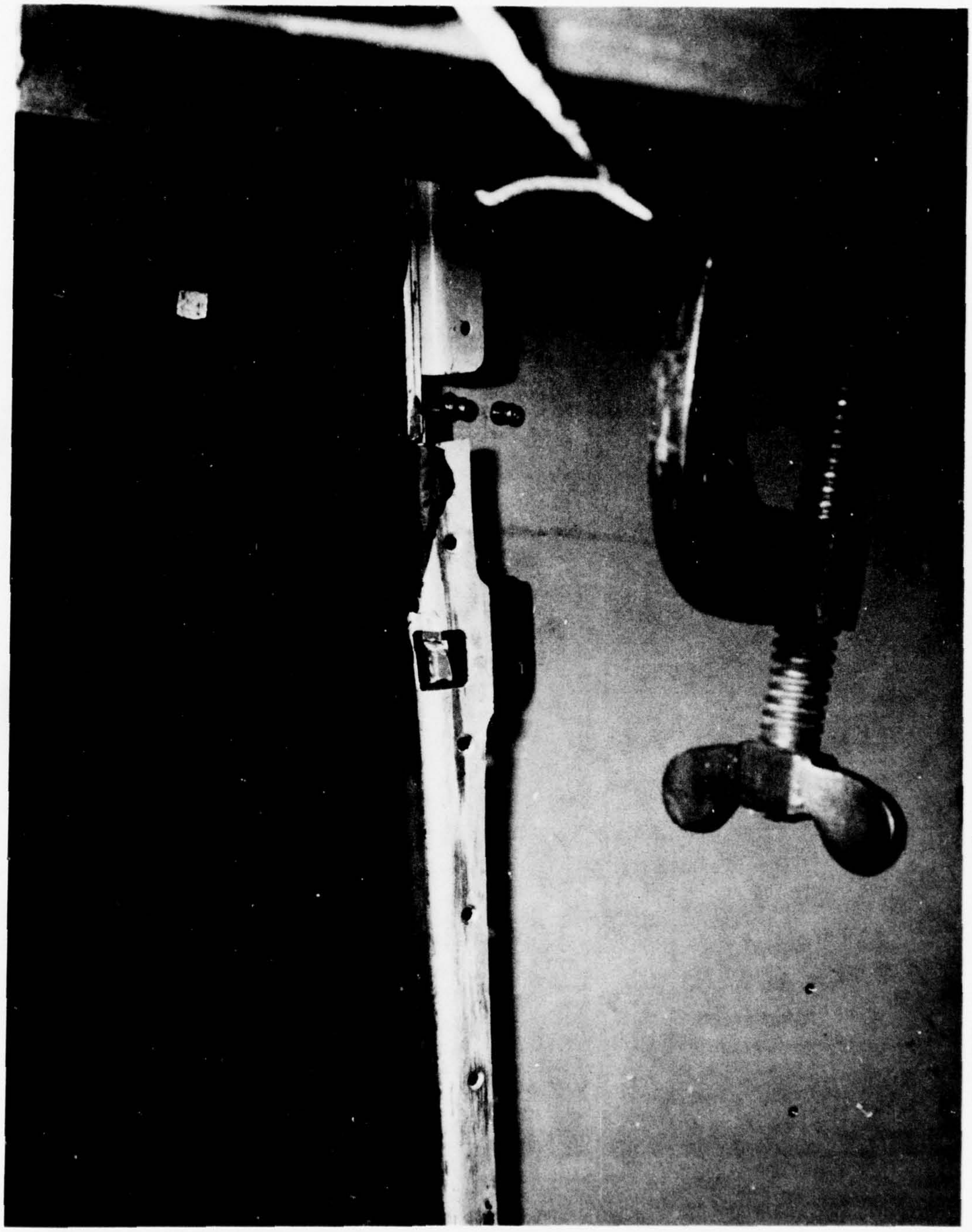

Figure 23. Canopy Support Fitting Installation - P/N 160D116049-12

Figure 24. Failed Canopy Side Rail

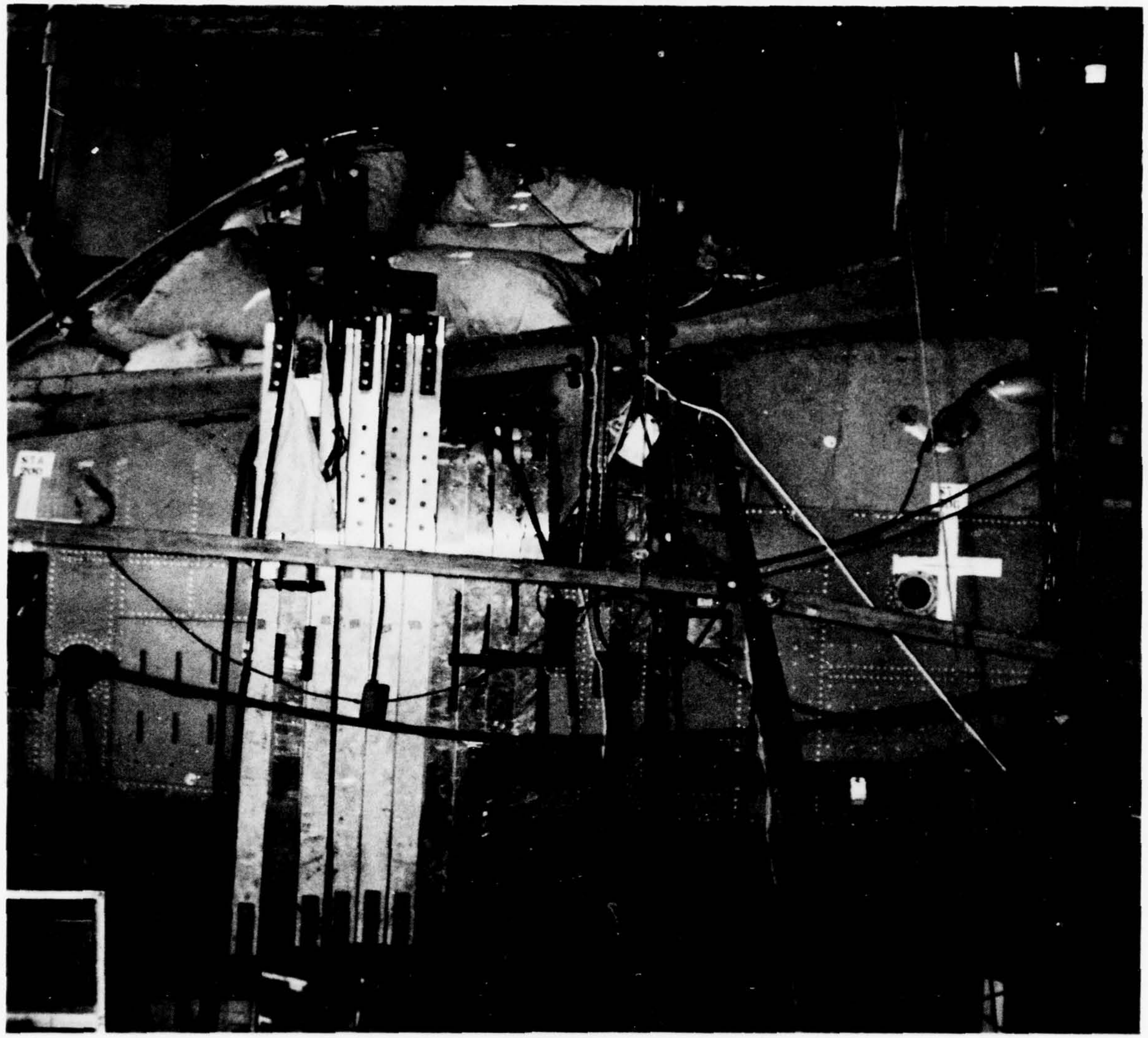

Figure 25. Failed Canopy

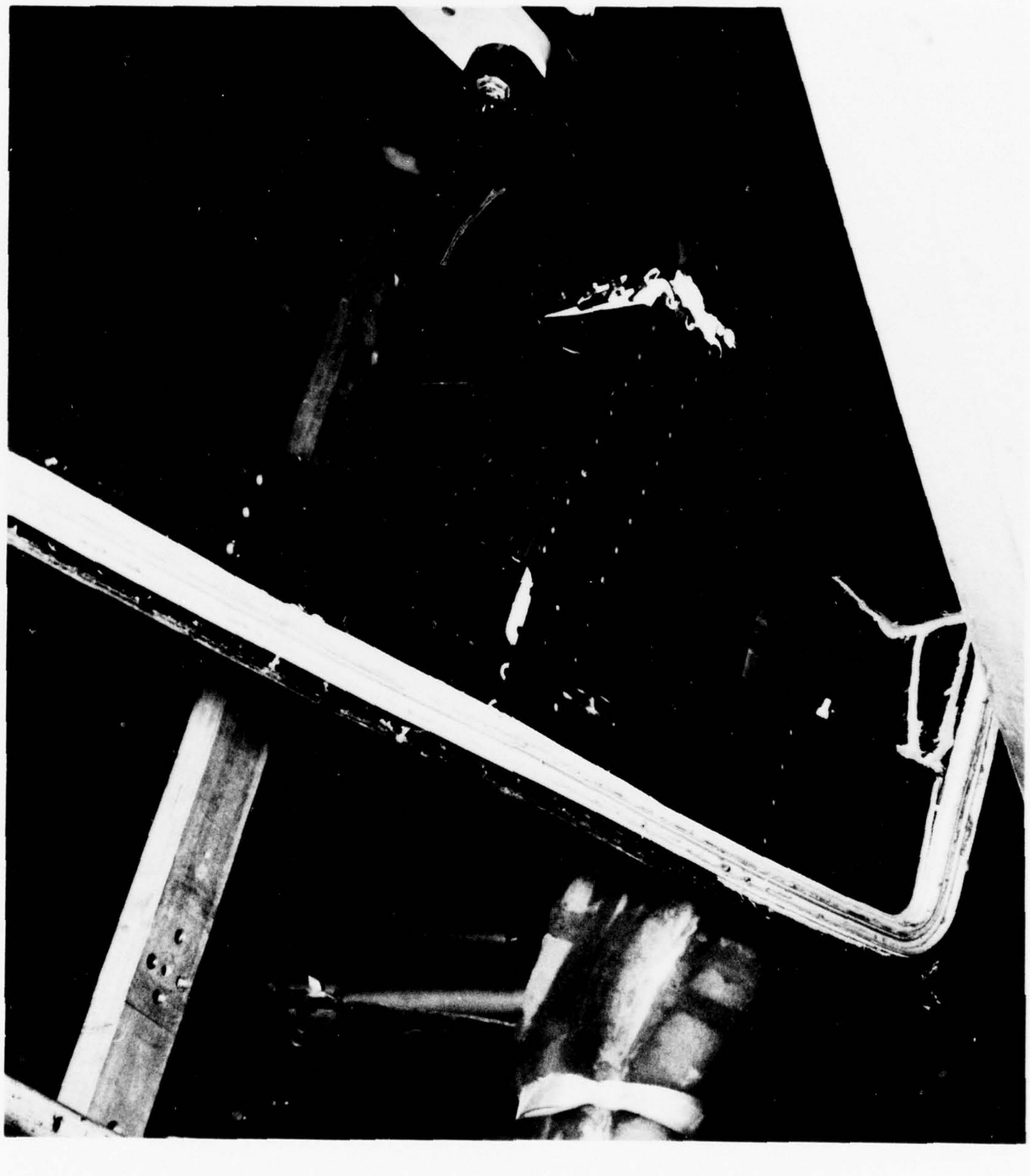

Figure 26. Failed Canopy Structure

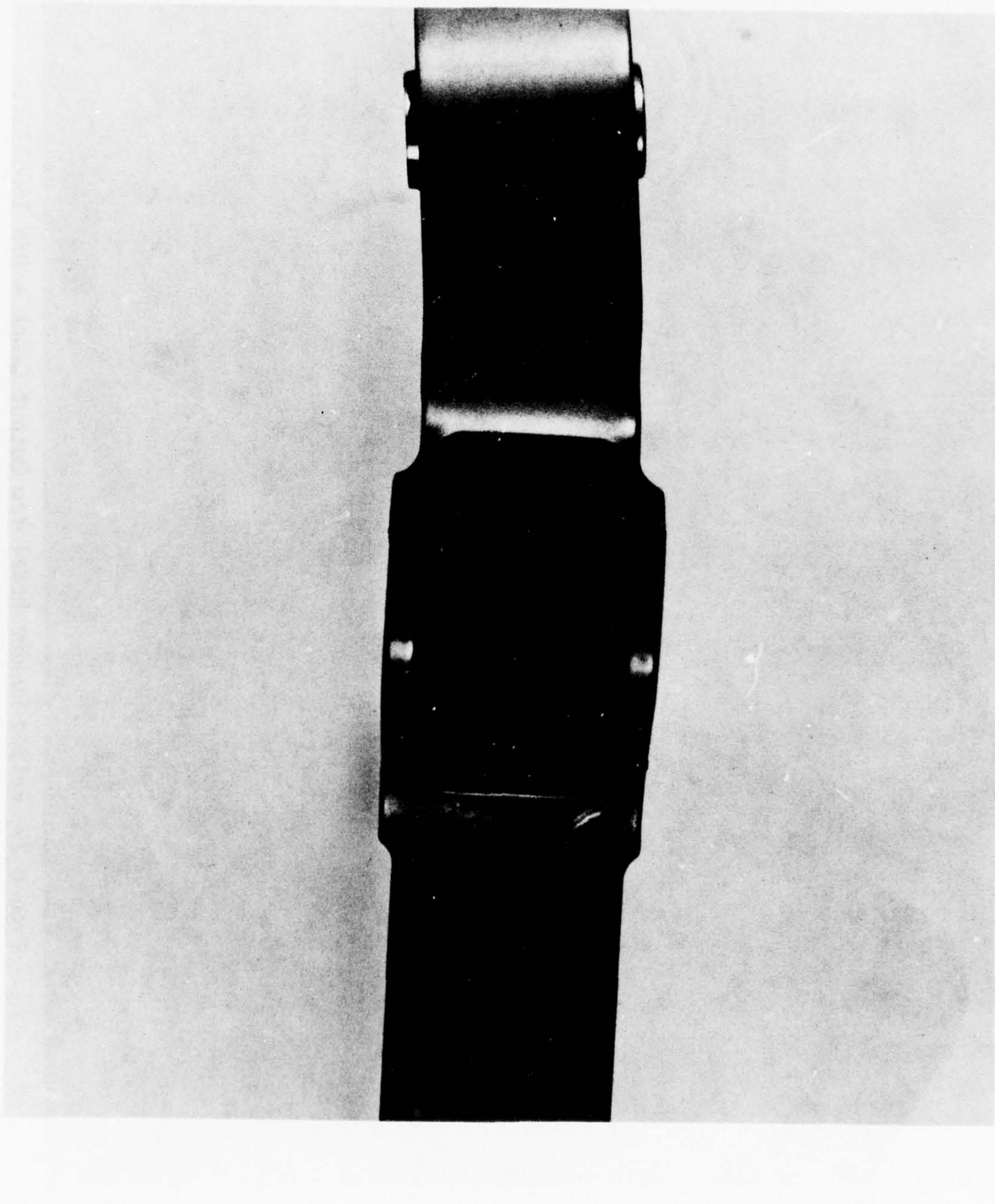

Figure 27. Failed Rudder Pedal Yaw Output Crank - P/N 160D123150

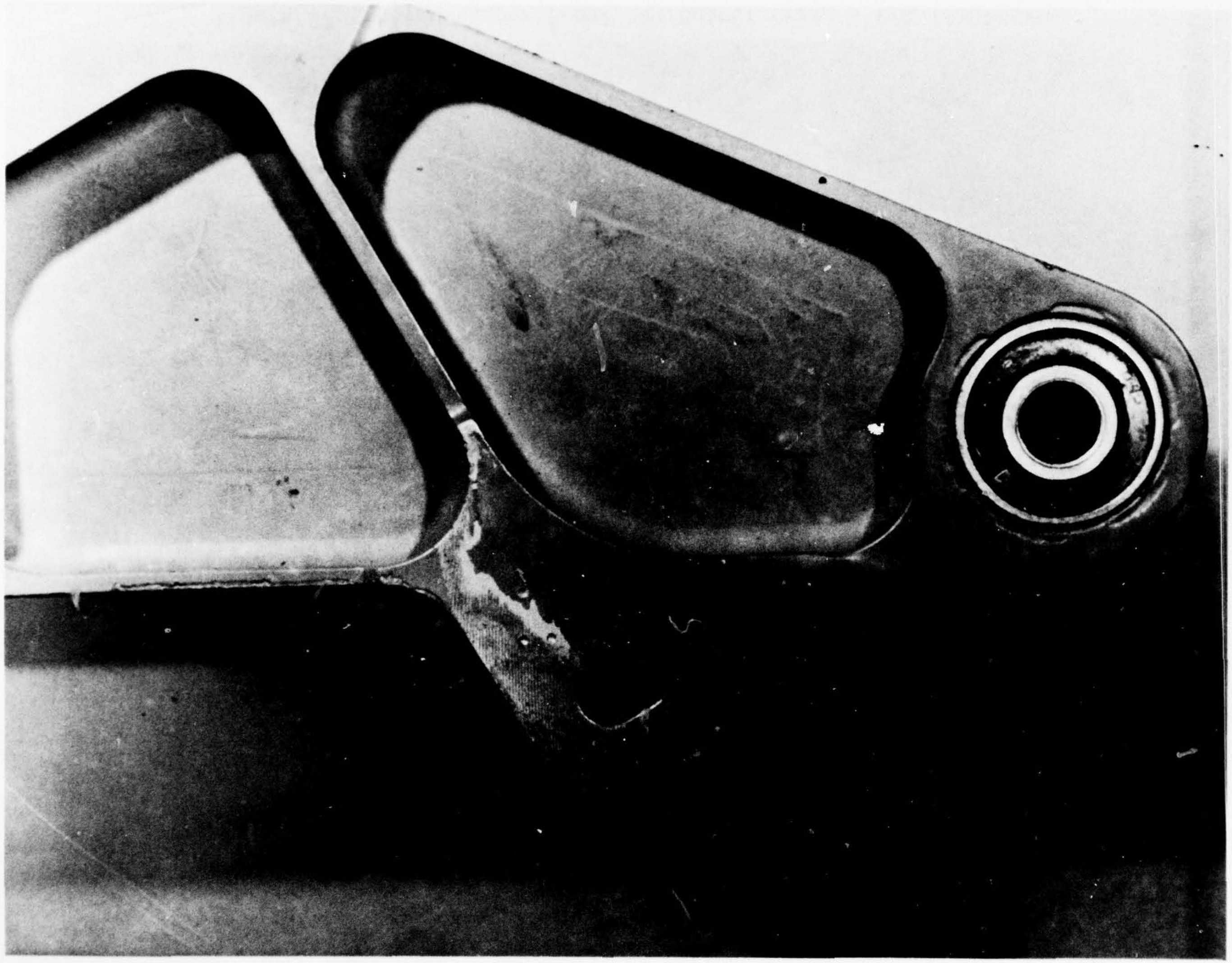

Figure 28. Failed Rudder Pedal Yaw Output Crank - P/N 160D123150

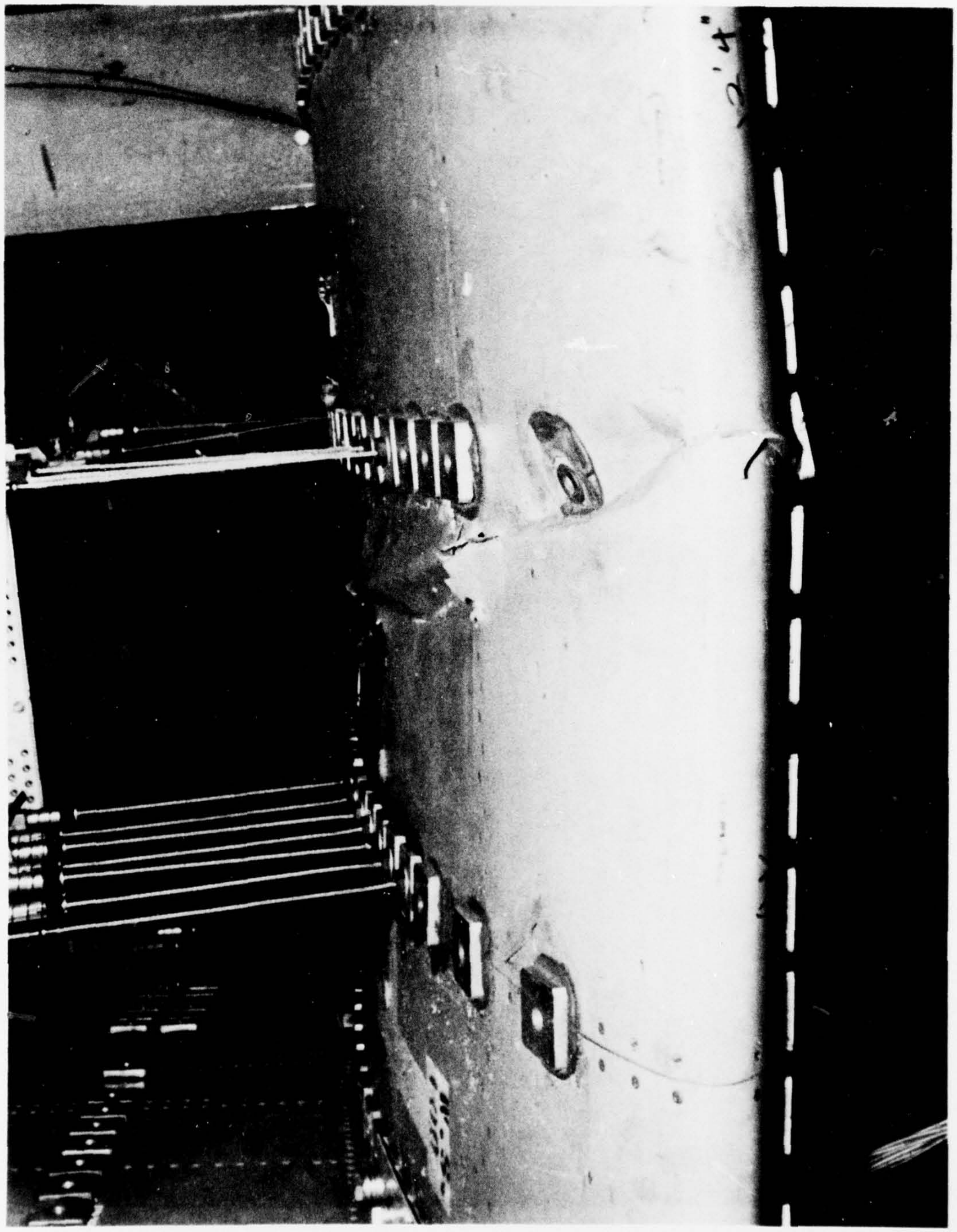

Figure 29. Right-Hand Horizontal Tail Upper Cover After Failing Load Test

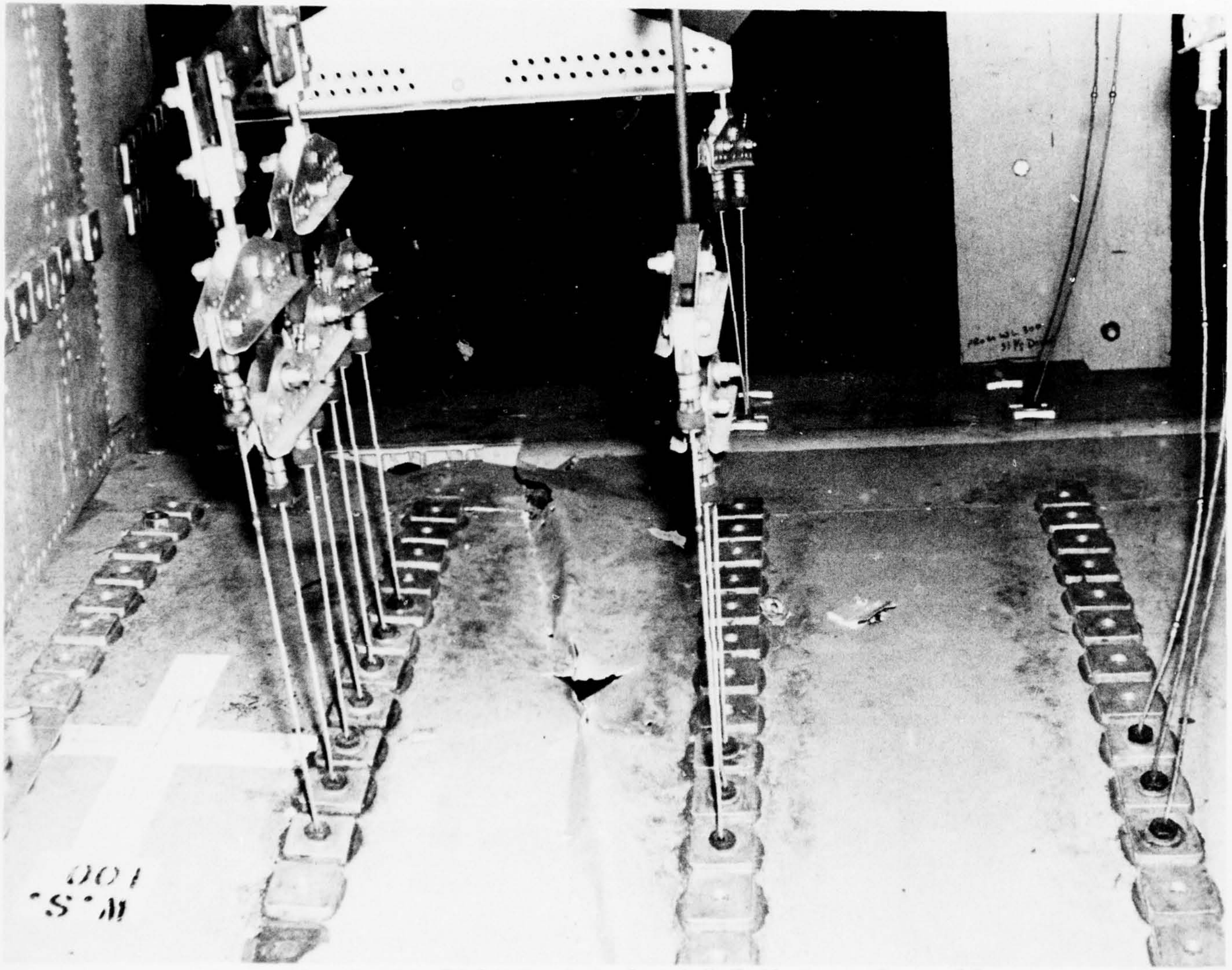

Figure 30. Right-Hand Horizontal Tail Upper Cover After Failing Load Test

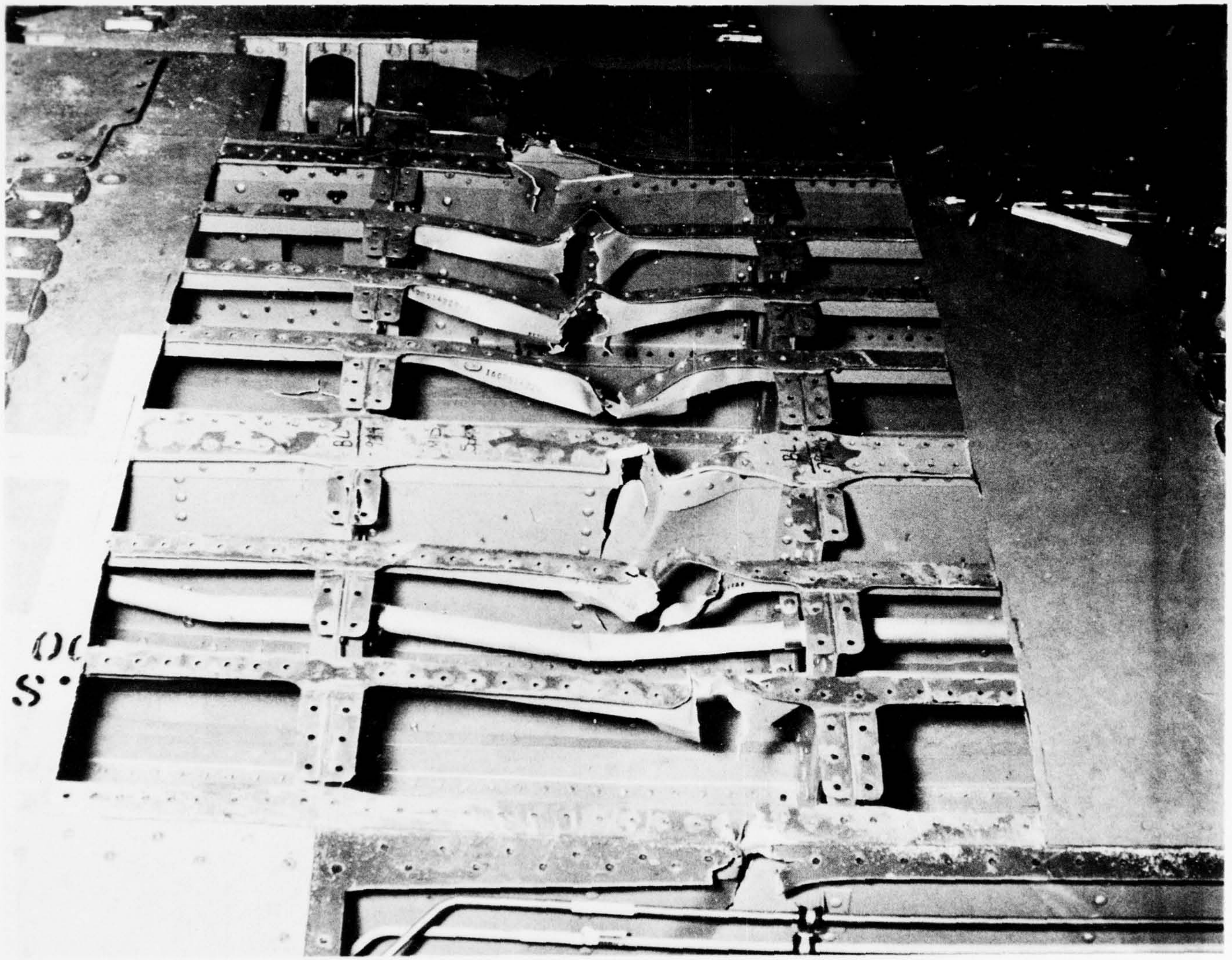

Figure 31. Right-Hand Horizontal Tail Spar and Stringer Damage After Failing Load Test

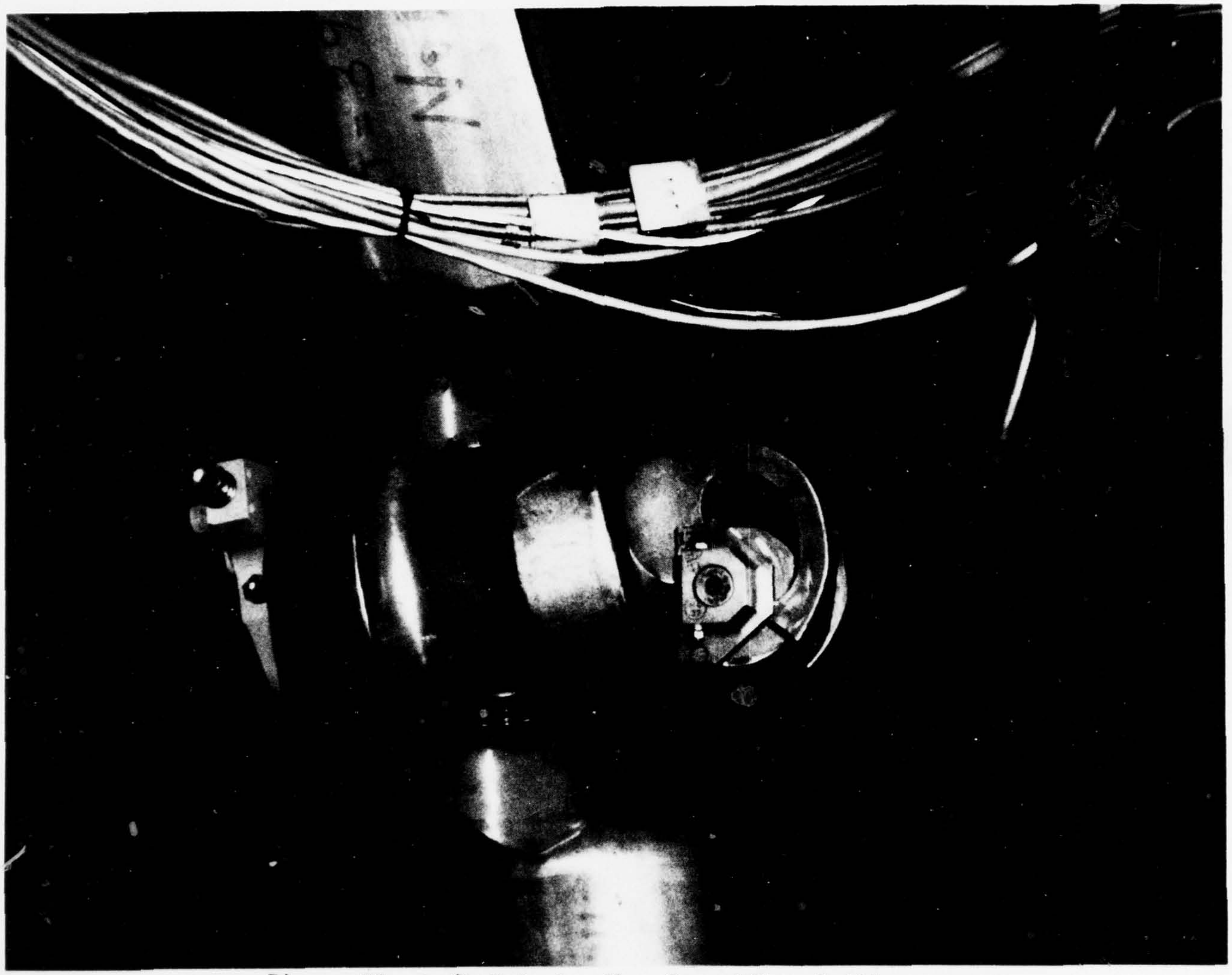

Figure 32. Left Main Landing Gear After Failing Load Test

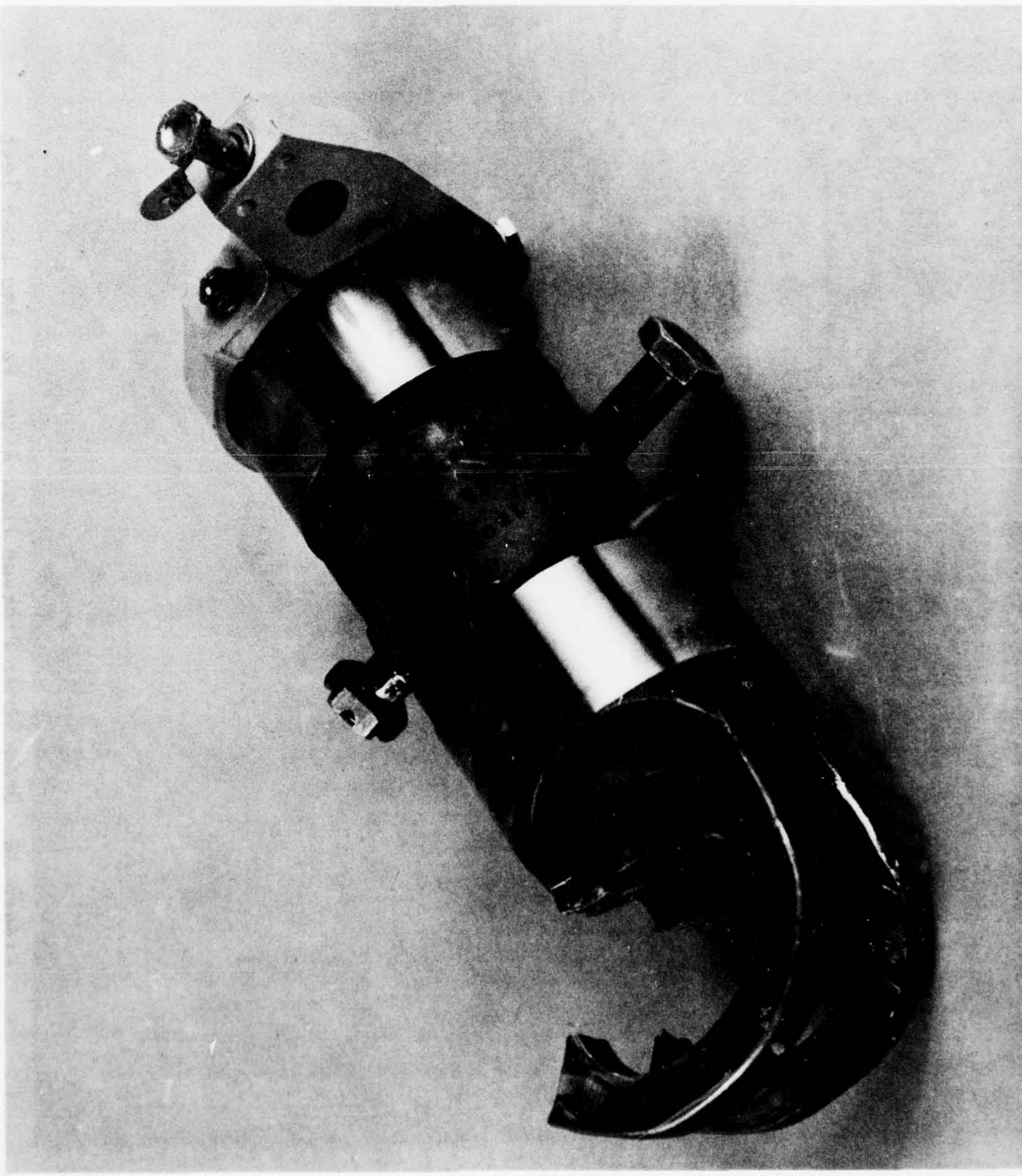

Figure 33. Socket Pin (Part No. 19062) After Failing Load Test

Figure 34. Drag Strut Pick-up Lugs After Failing Load Test

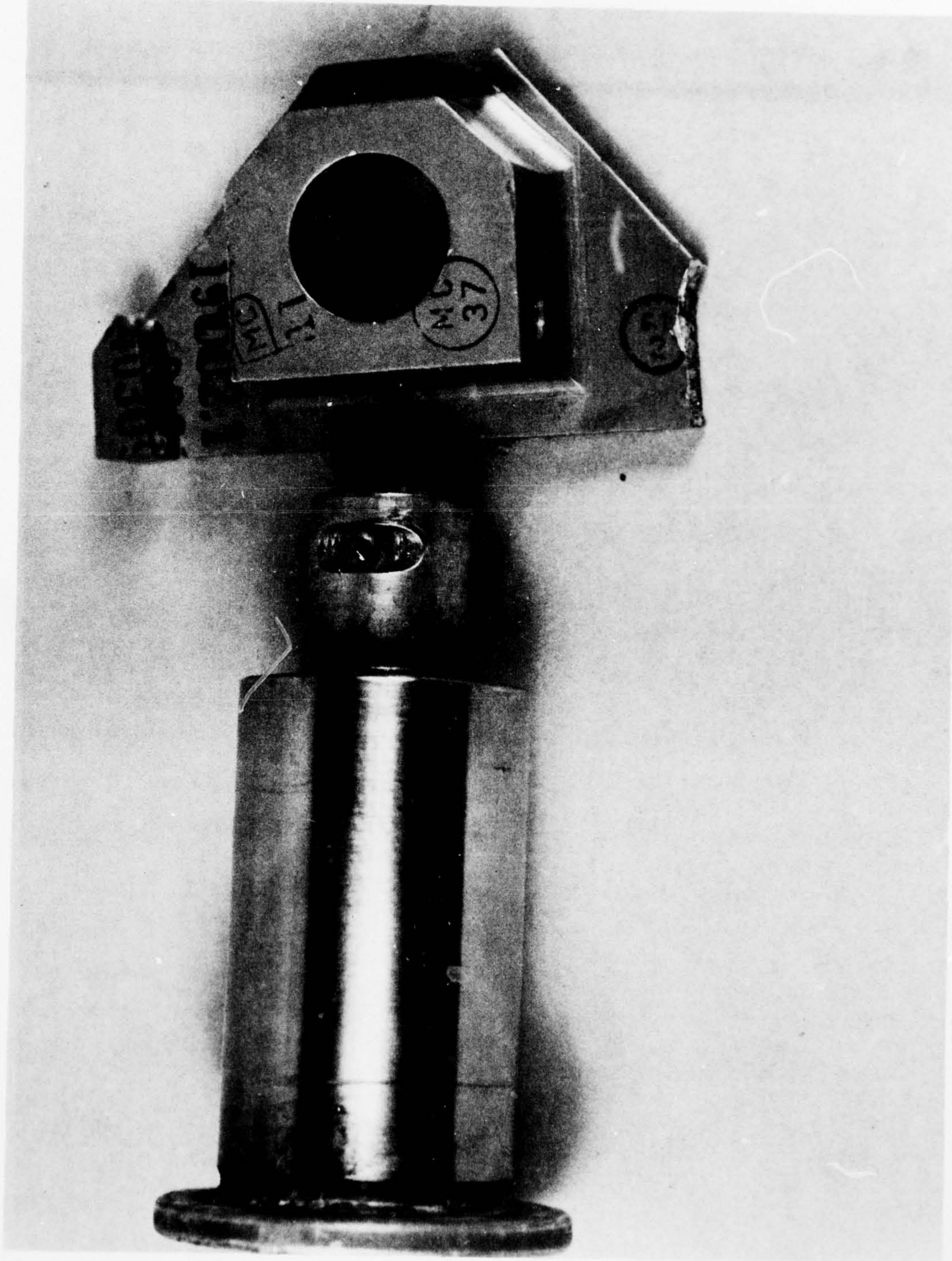

Figure 35. Drag Strut Pin (Part No. 19001) After Failing Load Test

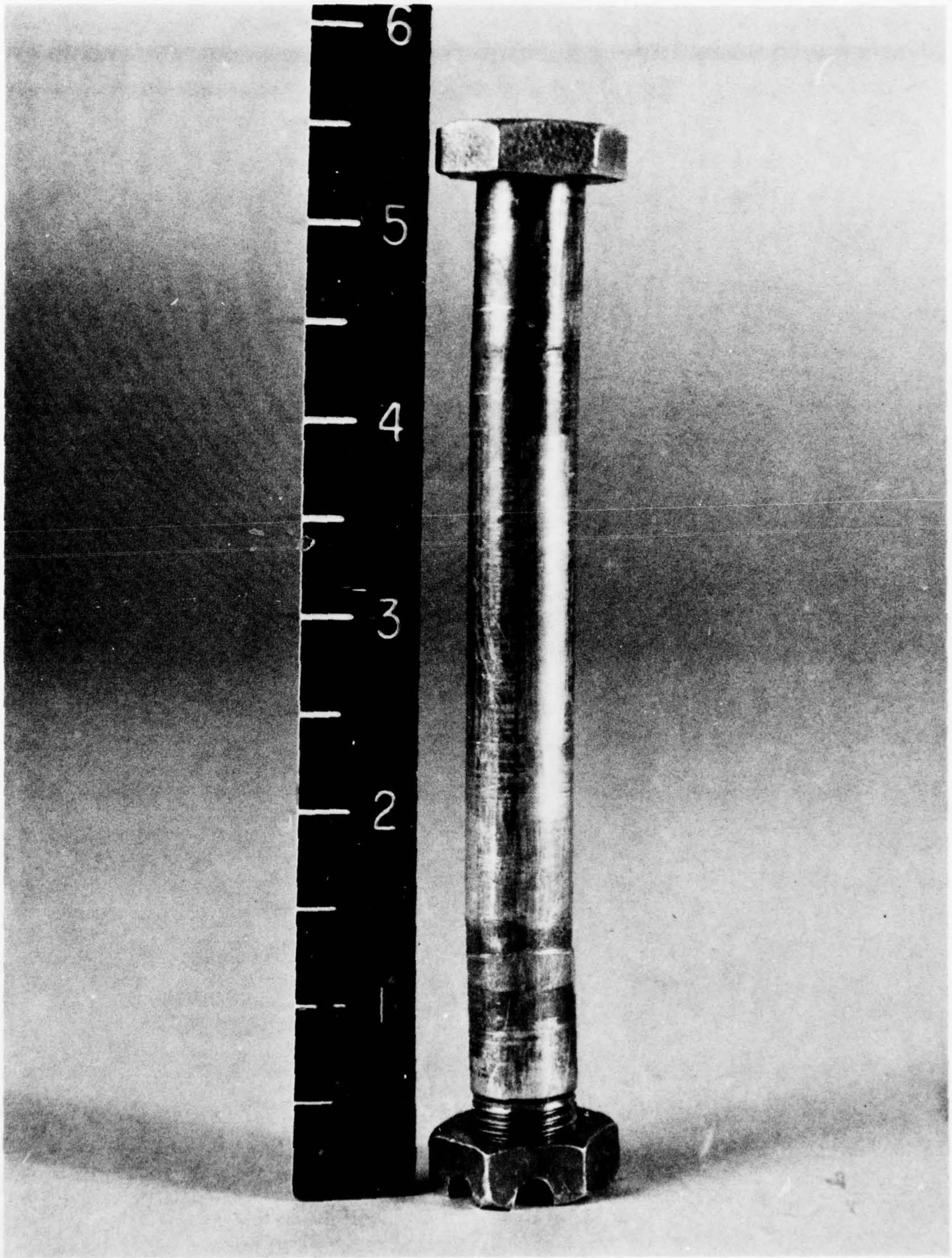

Figure 36. NAS 464P9-74 Bolt After Failing Load Test

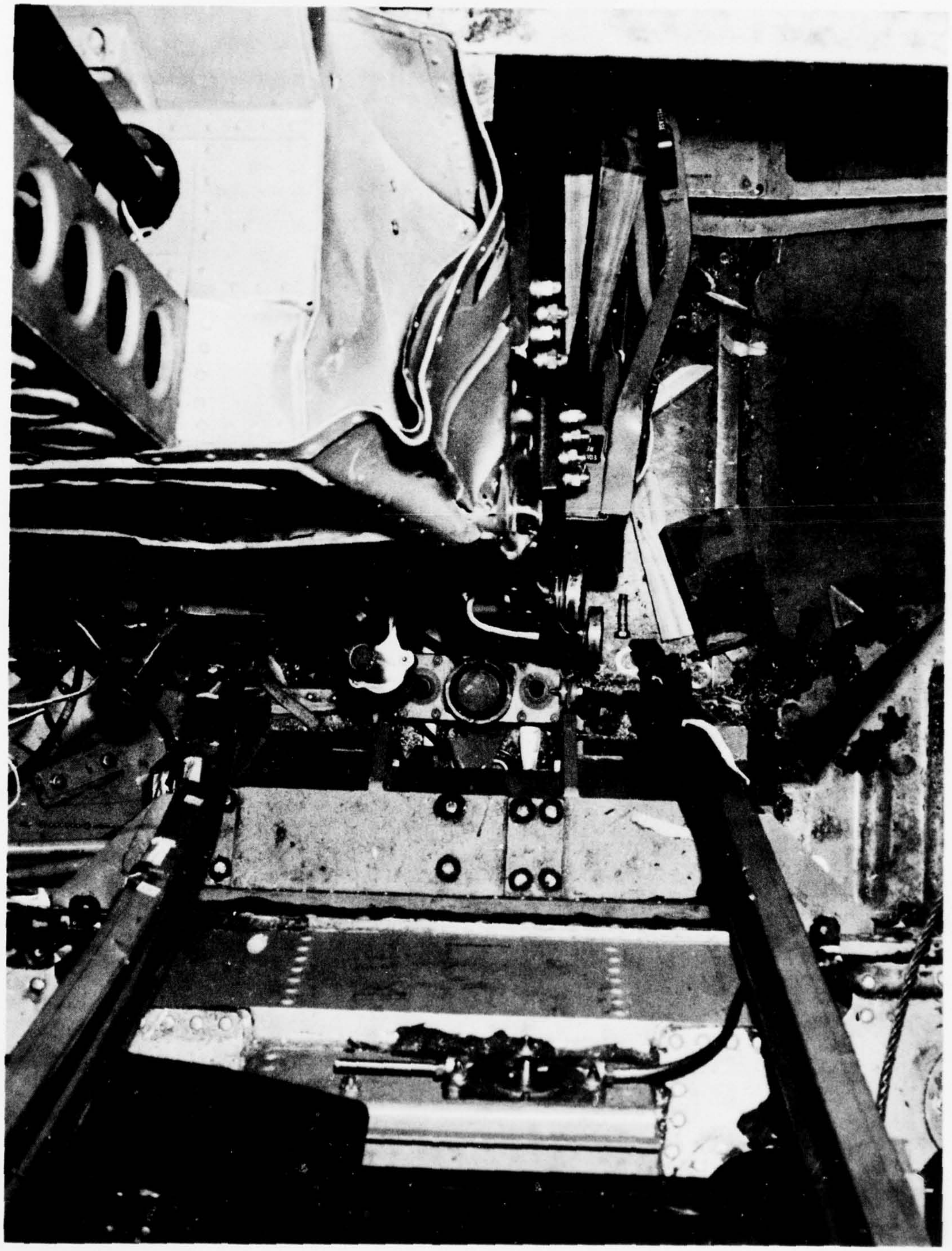

Figure 37. ACES II HTES Seat Support Structure After Failure

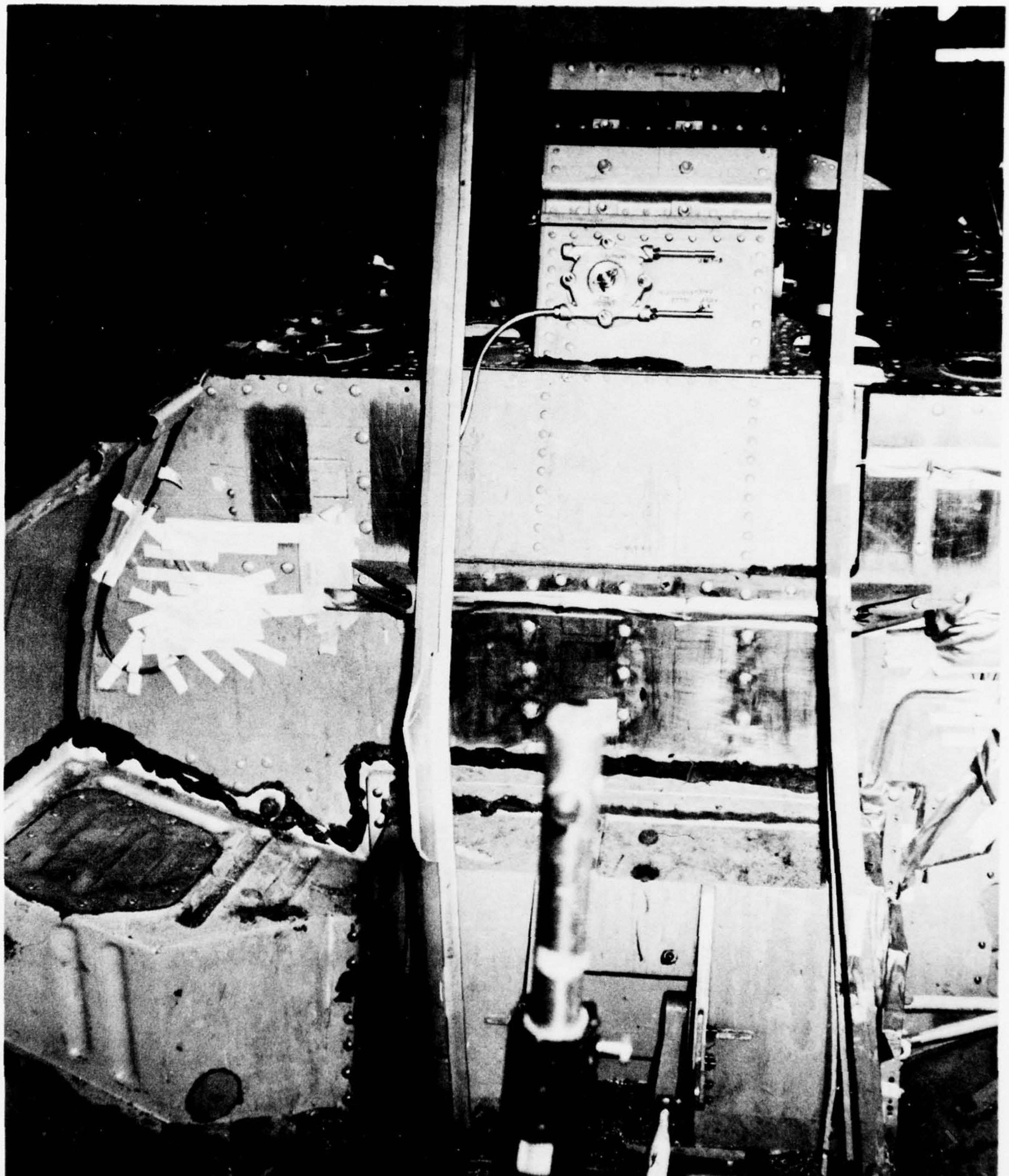

Figure 38. Seat Rails (Part No. 160D188065) After Failure

Figure 39. Support Casting (Part No. 160D116027) After Failure

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1. GT160W0049

   A-10 Full Scale Static Aircraft Test Plan - Addendum 1 to GT160W0047 - Balanced Aircraft Test Conditions PB-BDW/MFCG-750-05 (7.33g), RPM/RPDM-750-05 (5.86/3.0g)

2. GT160W0050

   A-10 Full Scale Static Aircraft Test Plan - Addendum 2 to GT160W0047 - Balanced Aircraft Test Condition PB-MTW-372-00 (5.0g), PDY-BDW-600-200 (7.33g)

3. GT160W0051

   A-10 Full Scale Static Test Plan - Addendum 3 to GT160W0047 - Elevator Component Test Condition PDY-MFCG-378-00 (4.5g)

4. GT160W0052

   A-10 Full Scale Static Aircraft Test Plan Test of Landing Gear Uplocks Doors and Fairings - Addendum 4 to GT160W0047

5. GT160W0053

   A-10 Full Scale Static Test Plan - Addendum 5 to GT160W0047 - Slat Component Test

6. GT160W0054

   A-10 Full Scale Static Test Plan - Addendum 6 to GT160W0047 - Engine and Nacelle Component Test Condition R-BDW-680-20-(-1.0g)

7. GT160W0055

   A-10 Full Scale Static Aircraft Test Plan - Addendum 7 to GT160W0047 - Balanced Aircraft Test Conditions NB-BDW-268-00 (-3.0g), NB-MTW/BDW-605-00 (-2.0g/-3.0g)

8. GT160W0056

   A-10 Full Scale Static Test Plan - Addendum 8 to GT160W0047 - Empennage Component Test Condition SSRR/OSMR-MFCG-363-00 (1.0g)

9. GT160W0057

   A-10 Full Scale Static Test Plan - Addendum 9 to GT160W0047 - Deceleron Component Tests

10. GT160W0058

    A-10 Full Scale Static Aircraft Test Plan - Addendum 10 to GT160W0047 - Flap Component Test at 20° Flap Setting

11. GT160W0059

A-10 Full Scale Static Aircraft Test Plan - Addendum 11 to GT160W0047 - Cockpit Pressurization and Canopy Wind Gust Loads Test

12. GT160W0060

A-10 Full Scale Static Test Plan - Addendum 12 to GT160W0047 - Landing Gear Support Structure Component Tests (Nose Gear and Main Gear)

13. GT160W0061

A-10 Full Scale Static Test Plan - Addendum 13 to GT1600047 - Pylon Component Tests Pylon Stations 0, 23, 66, 144, 187, and 230

14. GT160W0062

A-10 Full Scale Static Aircraft Test Plan - Addendum 14 to GT160W0047 - Primary Flight Control Systems

15. GT160W0063

A-10 Full Scale Static Test Plan - Addendum 15 to GT160W0047 - Aileron Geared Tab Component Test

16. GT160W0064

A-10 Full Scale Static Test Plan - Addendum 16 to GT160W0047 - Nacelle Main Accessory Compartment Door (Opened) Component Test

17. GT160W0065

A-10 Full Scale Static Aircraft Test Plan - Addendum 17 to GT160W0047 - Air Refueling Receptacle (UARRSI) Component Test

18. GT160W0066

A-10 Full Scale Static Test Plan - Addendum 18 to GT160W0047 - Ammunition Drum Support Component Test and Pave Penny Component Test

19. GT160W0067

A-10 Full Scale Static Test Plan - Addendum 19 to GT160W0047 - Jacking and Hoisting Conditions Component Tests

20. GT160W0068

A-10 Full Scale Static Test Plan - Addendum 20 to GT160W0047 - Demonstration of the Non-Binding Operation of the Flight Control Systems Test

21. GT160W0069

A-10 Full Scale Static Aircraft Test Plan - Addendum 21 to GT160W0047 - Landing Gear Pod

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22. GT160W0077

A-10 Full Scale Static Test Aircraft Test Plan - Addendum 22 to GT160W0047 - Failing Load Test Condition PB-BDW/MFCG-750-05 (7.33g)

23. GT160W0080

A-10 Full Scale Static Test Aircraft Test Plan - Addendum 23 to GT160W0047 - Failing Load Test Conditions for the Landing Gear Support Structure

24. GT160W0082

A-10 Full Sclae Static Test Aircraft Test Plan - Addendum 24 to GT160W0047 - Failing Load Test Condition for the Aft Fuselage and Empennage RPM-BDW-750-05 (5.86g)

25. GT160W0087

Structural Test Plan - ACES II HTES Seat Support Structure Test

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